DETERMINING THE SUITABILITY OF FUNCTIONAL LANDSCAPES AND

WILDLIFE CORRIDORS UTILIZING CONSERVATION

GIS METHODS IN DENTON COUNTY, TEXAS

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Denton County's unique cultural and natural landscape has undergone dramatic transformations during the past two centuries due to agricultural, urban and suburban processes which accelerated the loss and removal of native habitat and wildlife. This research sought out to identify the remaining natural areas which retain their natural features and support wildlife. Research methodology included fundamental principles of Conservation Planning, Geographical Information Systems, and Habitat Evaluation Procedures for identifying remnant functional landscapes and wildlife corridors. The final results suggest that Denton County's rural landscape retains the functional properties and elements suitable for habitat conservation and wildlife corridors, while also pointing to the fundamental obstacles to conservation posed by continued growth and private landownership.

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CHAPTER I

INTRODUCTION

Present-day Denton County and the surrounding North Texas landscape have undergone tremendous, irreversible transformations from their ontological, pre-historical conditions to the current state of habitat degradation, fragmentation, wholesale removal of species, pollution of waterways and other associated effects of modernization. In response to the pervasive loss of natural places, space, native flora and fauna, this paper hopes to address solutions to the growing body of environmental ills seemingly pandemic to the modernizing world. There is a felt urgency to respond delicately yet assertively with respect to preserving natural landscapes which remain today from further development and degradation, a need that may be overlooked even today as remnants of the pioneer land speculator ethic is still prominent in real estate transactions, in highway projects dotting the North Texas landscape, growing landfills replacing natural vistas, and the noticeable absence of most native wildlife to this area. If one wishes to find some semblance of a natural landscape one must drive to the rural countryside, and often much further, to find remote areas where degradation and destruction of the environment is not pervasive. Even then the historical natural roots of North Texas could rightfully be asserted to be lost or irretrievable. However, the basis of this paper is that natural areas remain in Denton County and the surrounding landscape where their functional and structural properties warrant preservation, and where conservation plans currently exist there is a need to expand park and reserve boundaries to adequately safeguard the species who reside in and migrate between them.

The guiding framework for analysis addressing preservation of functional landscapes and conservation areas is anchored in geographical analysis yet equally a hybrid of geographical thought and methodology weaving together conservation, land-use planning, Geographical Information Systems (GIS), environmental policy, and wildlife ecology in order to grasp the full breadth and depth of the environmental problems we face today. For the purposes presented here it can be said to be the emergence of Conservation Geography, a still new concept and application to the traditional body of geographical thought and ideas also driven by the growing need to tackle applied problems of habitat and wildlife conservation comprehensively and effectively (Society for Conservation GIS, 2007; ESRI, 2007; Lang, 1998). The primary methodology used for this paper is spatial modeling through ArcGIS 9, Habitat Evaluation Procedures (HEP), Environmental Assessment, and Reserve Design supported by collaborative theoretical, quantitative and qualitative analysis. With the general premise to find functional landscapes it was hoped that understanding natural space and places would become possible from a geographical standpoint in an applied and theoretical construct equally. The central thesis of this research, therefore, is that Denton County's rural landscape retains functional properties and elements suitable for habitat protection and wildlife corridors, including vegetation, presence of wildlife, low human impact, aesthetics and unique or rare landscape elements.

CHAPTER II

LITERATURE REVIEW

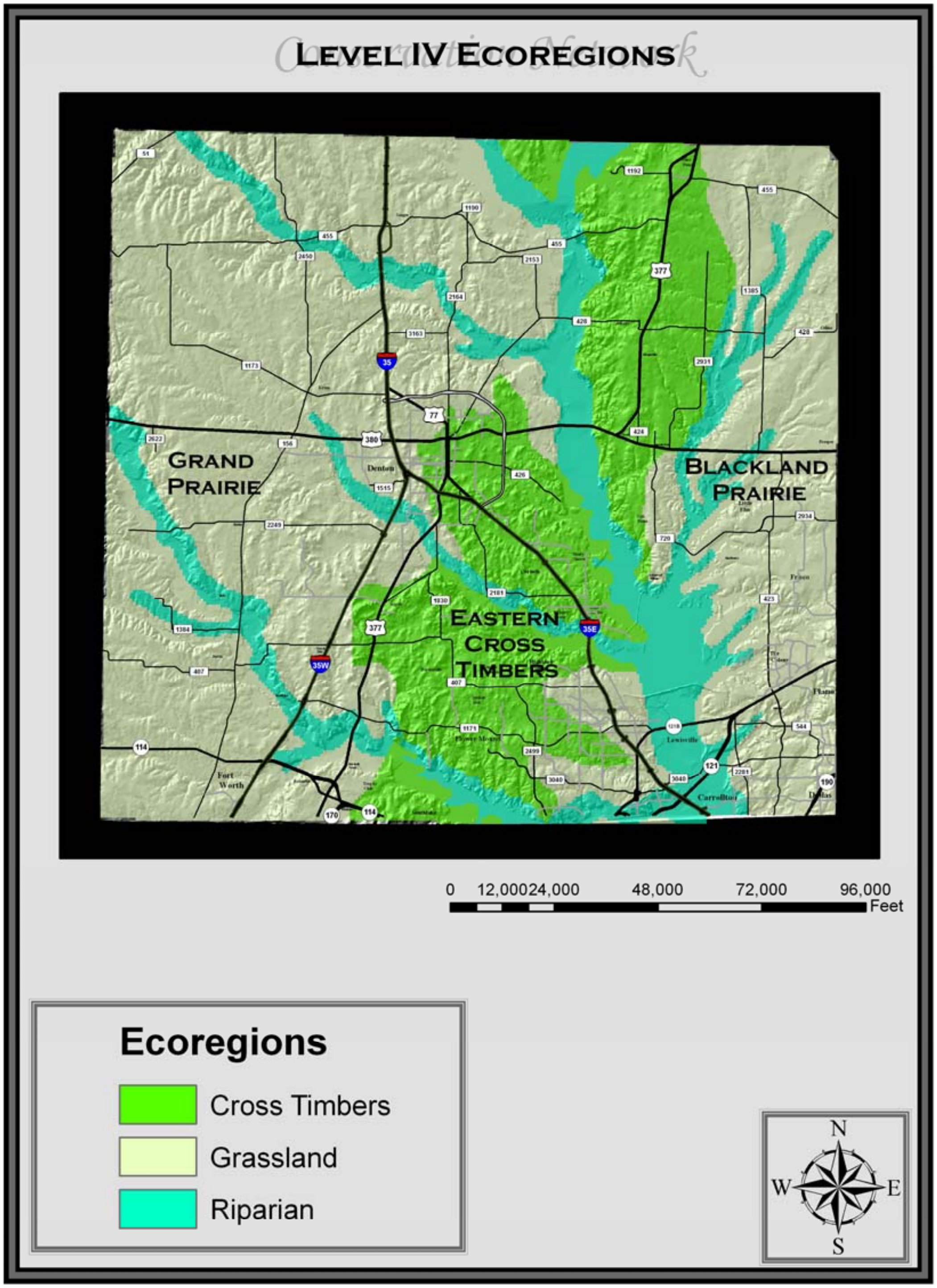
In the past two centuries the North Texas landscape has transformed from a dynamic and diverse composite of ecosystems and cultures to an overwhelmingly homogenous landscape of metropolitan and agricultural areas obscuring the native landscape. After two centuries of conversion, fragmentation, and eradication conservation efforts were slowly beginning to emerge only recently. In the past few decades our ecological resources have gained attention the attention of public, private, state, and federal agencies respectively. The Texas Parks and Wildlife Department (TPWD) is one of the forerunners of devising a comprehensive plan for conserving not only Texas' natural ecosystems but also the diverse flora and fauna which inhabit the state (TPWD, 2005; TPWD, 2006). Texas is divided into 10 ecological regions, two of which are critical to Denton County: the Cross Timbers and Prairies, and the Blackland Prairies. Prior to Anglo-American settlement in the 1800's the Cross Timbers and Blackland Prairie ecoregions were occupied by a diverse mix of indigenous tribes, and one of the most diverse ecological landscapes in the U.S. With the conversion of native habitats and removal of most native species from Texas also came the plow, railroad, and much later in time highways, metropolitan areas, dams, oil and gas wells, and utility facilities which would culminate into a landscape created almost entirely by humans. However, within this landscape exists natural preserves, rural open space, riparian corridors, wetlands, and wildlife that all too often are taken for granted.

The environment we see today- the habitat at our hinterlands between cities, the roaming wildlife visiting our homes and ranches, the occasionally-vibrant rivers and streams- are all a mere semblance of a once intact, interlocking system separated from our collective consciousness and history by only two centuries. Today we can look out into the horizon, either from a scenic vista or most often from our cars as we drive along county roads if not major highways, and be completely disconnected from the life that once defined the area. The landscape today is conveniently divided into finely drawn parcels defining who owns what piece of land, severely dissected by ever-growing roads reaching into nearly every part and parcel of the county as urbanization is superceded by a similar process of suburbanization, whereas most areas are now susceptible to the wonton energy hunger for a mysterious geological formation, the Barnett Shale, lying underneath our plants and soil containing rich yet limited deposits of natural gas. The land may be more susceptible to fragmentation and conversion today than ever before so much that natural habitat and wildlife are considered by most as too marginal to feel compelled to protect, too distant from our collective history to neither remember nor encounter (Taylor, 2006). Three specific landscape processes drive this process of elimination and separation and are fundamental to this paper: subdivision growth, development and expansion of roads, and the blooming natural gas industry. All three contribute substantially to the loss of habitat. For example, in 2004 the commissioners of Denton County felt compelled to devise a committee to assess natural gas wells steadily converting natural habitat, the Oil and Gas Task Force. Their findings showed that from 1995 to 2004 the number of gas wells grew exponentially from 156 wells to 1,460 wells in a nine year period, coupled with a dramatic increase in mineral wealth from $88,786 to

$2,731,324 in 2004 (Oil and Gas Task Force, 2005). As of the beginning of 2007 there are now 1,820 gas and oil wells as the industry continues to thrive in a political environment of minimal regulation and restraint as every municipality attempts to counter the emergence of gas wells close to our homes and schools, along our natural streams and waterways, and most often dissecting habitat too remote from our awareness to prompt a sufficient and effective response (Crowe, 2007). Likewise, exponential growth of subdivisions fuels the uncannily familiar process of suburban sprawl with the ensuing destruction of natural habitat and the displacement of numerous wildlife inhabiting these once natural areas. Furthermore, during the writing of this paper the Texas Department of Transportation, with the support of Governor Rick Perry, proceeds with a statewide plan to develop new roadways along currently roadless areas and with minimal consideration to local habitat and wildlife as evident in their Tier I Trans-Texas Corridor Study (US DOT & Texas DOT, 2006).

In order to address these substantial changes to the landscape and wildlife we must penultimately reflect backwards into the region's collective past, one that we only know through scientific and historical research of radically different environment than we experience and perceive today. The full breadth of regional and local history is difficult to apprehend without the rich cultural narratives and history of the changes it endured from its first documented encounter through the dynamic settlement period of the 19th century to the present day. Our natural ecoregions, habitat, and native wildlife were fundamental emblems and symbols to the first people who occupied this region and no less to the pioneers who came to settle and tame the region.

Figure 1: Denton County's natural ecoregions: Grand Prairie, Cross Timbers and Blackland Prairie. Additional coverage of riparian habitat is included to depict natural waterways.



Prior to the pioneer settlement Texas was inhabited by a diverse array of Native American tribes who would remain until the final decades of the 19th century. North Texas and Denton County were occupied primarily by the Kickapoo, Kichai, Hainai, Comanche, Caddo, Wichita, and Tawakoni while members of other tribes were often present and mixed into the cultural scene before and during the first contact with Texas pioneers (Berlandier, 1969; Gannett, 1984). The earliest accounts of Denton County settlement are perhaps most informative and indicative of the historical natural landscape defined by the persistent tensions between native inhabitants and the new waves of settlers. Prior to 1826 the area was considered Indian Territory by the Spanish and Mexican governments after portions or all of Texas traded hands between them (Bates, 1976). Denton County was also part of Red River County, and later part of Fannin County, until it became officially recognized in 1846. It was during this time that the Peters Colony settlers began occupation of Denton County and the surrounding North Texas landscape to compete with native tribes for land. In 1841 the 5th congress of Texas issued land grants for incoming settlers ranging between 320 and 640 acres depending upon one's marital status (Bates, 1976). Accounts from the Peters Colony settlers at this time describe both the cultural and natural environment prior to its subsequent rapid conversion we now know today. Tribes still occupied significant environmental landmarks throughout the county, especially high elevations or lookouts, such as Pilot Knob and Pilot Point. Furthermore, the Blackland Prairie ecoregion along the eastern portion of Denton County was considered prime hunting grounds by the tribes, supporting a diverse array of wildlife, including Bison, along the Elm Flats (Bates,1976; Connor, 1976). These environmental features would quickly gain attention of the Peters

Colony and subsequent settlers as primary areas to settle, leading to on-going raids and wars between local tribes and the newly found Texas republic. Tribes would persistently raid settlements along Clear Branch, Big Elm, Clear Creek, Marshall's Creek, and Denton Creek until the last Comanche raid in 1871 (Bates, 1976; Gannett, 1984). As Pilot Knob became a picnic area for settlers so, too, would the Elm Flats, Pilot Point, and eventually every area of Denton County's ontological landscape. The defining ecoregions of this area-Eastern and Western Cross Timbers, and the Blackland and Grand Prairies- would become cultural icons to early settlers as areas to be conquered and subdued. During this phase the Texas congress expanded the settlement contracts and continuously disputed land ownership while displacing tribes from the area (Connor, 1959). It was part and parcel of a wider movement to depopulate the native inhabitants- both human and animal- and convert the native landscape to agriculture, timber production and pasture. In less than a decade the predominant land ethic in North Texas, as well as throughout the state, transformed from one of cohabitation of people and nature to a pandemic "land spectator" attitude and ideology that would shape the natural environment resemblant of contemporary attitudes towards the land as a resource of ownership and exploitation (Bates, 1976). It marked the end of an era where functional landscapes would appear to be forever altered and the need for conservation, and later preservation, of functional landscapes, natural resources and wildlife would become necessitated.

Once the initial settlement process mentioned above was complete the state of Texas became 95% privately owned, now considered to be one of the more prominent obstacles to conservation of land and wildlife. Pioneer settlements in North Texas arrived with two waves, one of Upper Southern cultures on the margins of the Cross Timbers, and the second of Midwestern cultures settling the open prairies (Jordan et. al., 1984). The major conversions of the landscape perhaps occurred between 1840-1900 via intensive agricultural production and the replacement of natural vegetation with crop monocultures and grazing territory for livestock (McDonough, 2000). However, the 20th century would bring a new type of anthropogenic landscape of unprecedented proportions in Texas with the emergence of major metropolitan areas. Not only were monoculture crops replacing natural vegetation but also concrete roads, interstates, massive turnpikes, railroads, powerlines, and expanding municipal land use jurisdictions were replacing or leveling natural topography, vegetation, mammals, waterways, and soil from Dallas south to San Antonio and outwards to the Gulf Coast. This newly created landscape in its modern form is commonly referred to as urban sprawl (Gunter & Oelschlaeger, 1997). In less than two centuries Texas experienced a "total humanization of earth's surface" with the emergence of cities, canals, forest clearing, fenced grasslands, agriculture, and the systematic elimination of native megafauna (Oelschlaeger, 1991:8).

As the Texas population continues to rise in the 21st century so, too, does the demand for land to be converted either to agricultural production, energy extraction, suburban developments, and urban use at the expense of remaining natural habitats and native wildlife. The Cross Timbers and Prairies region has been particularly impacted with over 64% of the original landscape being converted to modern use (TPWD, 2005:

Map 32). Similarly, the Blackland Prairies ecoregion has witnessed a more dramatic rate of conversion at 75% except with an even more disastrous effect of only 5,000 natural Blackland Prairie in existence today, in part due to less resistance in land clearing compared to forest clearing and its rich, dark soils ideal for agricultural crops (TPWD, 2005). Locally only 150 acres of native tall-grass Blackland Prairies remain protected in Collin, Dallas, and Denton County combined (Eidson & Smeins, 2005). However, Cedar Hill State Park (CHSP) retains one of the largest tracts within its boundaries to help ensure its survival provided sound prairie management is emphasized (TPWD, 2005). Both the Cross Timbers and Blackland Prairie are widely considered to be invaluable ecological assets by local, state, federal, and international groups, such as the TPWD, Nature Conservancy (TNC), and World Wildlife Fund (WWF). The Cross Timbers is a highly functional ecosystem within the Central Forests and Grasslands Biome, now included within a pragmatic array of conservation strategies to protects its natural plant communities and wildlife (Robinson et. al., 2001). Similar efforts are evident in the Ancient Cross Timbers Project as a coalition of states from Kansas south to Texas and between several universities from each participating state seeking to protect the distinctive biome separating the Eastern Deciduous Forests from the Great Plains (Stahle, 2005).

Tragically, most native megafauna, such as bears and bison, have been extirpated from most or all its native habitat consistent throughout Texas. Others species have proven more resilient yet remain threatened by the continuous fragmentation and encroachment. The current listing of the Golden-Cheeked Warbler as endangered and the Bald Eagle as threatened illustrate the importance of devising conservation strategies at the ecoregional level considering that many species with specific niches and requirements will depend upon the integrity of systems larger than mere blocks of habitat, and quite often spanning across several states, regions, and counties (Turner, 1997; TNC, 2004).

The Cross Timbers and Prairies ecoregion described in the TPWD report has been divided into more distinctive ecosystems at a smaller scale that will be used throughout this research paper: the Western Cross Timbers, Grand Prairie, and Eastern Cross Timbers (from west to east respectively). Meanwhile, the Blackland Prairie will retain its unique definition considering its' threatened status and limited geographical extent. On a more localized scale habitat type may be of greater importance to conservation strategies with respect to their more finite boundaries and interspersion with a variety of distinct, often isolated patches. Whereas the ecoregion assessments may fail to detect small-scale and local threats scaling down to habitat types may allow resource managers and developers to identify priority ecological areas (Allen & Hoekstra, 1992). Of equal importance in this paper are riparian forests which function as highly productive habitat, but also as wildlife corridors. Riparian forests were identified as high priority habitats by the TPWD statewide conservation plan and often appears in local land use master plans (TPWD, 2005; City of Denton, 2000; Flower Mound, 2001; Parker et. al., 2003). Most species may actually rely upon riparian habitats for most of their survival requirements, especially as sources of water and the high vegetative productivity of bottomland hardwood forests and wetlands (Hoffman, 2001; TPWD, 2002; Barry, 2000; Holcomb, 2000; Krueger et. al., 2001). Habitat types will be covered within the study area as conglomerate ecosystem types, such as forest, grassland, shrub, and savanna rather than

Table 1: Level IV Ecoregions in Denton County and their natural characteristics.

Ecoregion	Region	Geology	Soils	Vegetation
Grand Prairie	Western portion of County	Limestone, Shale, Marl	Mollisols	Tall & Short Grasslands: Big & Little Bluestem, Sideoats Gamma, Buffalo Grass, Texas Winter Grass
Eastern Cross Timbers	Central portion of County	Woodbine Sandstone	Alfisols	Oak Woodlands: Post Oak, Blackjack Oak
Blackland Prairie	Eastern portion of County	Eagleford Shale, Austin Chalk	Vertisols	Tall Grasslands: Indian Grass, Switch Grass, Big & Little Bluestem

individual plant communities- post oak-live oak, bluestem, and blue gamma- unless clear delineation of their extent was possible through secondary land cover classifications and field verification.

With respect to ecosystems and conservation the key strategy becomes land protected primarily or solely for the purpose of preservation. These Functional Conservation Areas (FCA's) may be everything from private nature reserves to a state or federal park (TNC, 2004). Each type of FCA will possess different advantages and disadvantages, such as intensive management and control of ecosystems and wildlife in National Parks, otherwise defined by its sheer size covering millions of acres. FCA's are central to conservation efforts as the quintessential nodes where native flora, fauna, and landscape features will be more insured from development and degradation (TNC, 2004). By emphasizing existing protected lands a methodological assessment of the surrounding landscape may ensue, either in search of threats immediate to the FCA or in search of landscape linkages, or corridors, to surrounding natural areas. Reserve Design has been implemented in regions of large wilderness tracts, parks, refuges, and private lands throughout the U.S., best exemplified by the Wildlands Project (Noss, 2003; Forman, 1995). An inspiring regional example of designing conservation networks continues to draw attention in the Sierra Nevada Ecosystem (Stoms, 2003).

Most examples and applications of designing conservation networks come from regions with existing protected areas and public land, without which planning becomes more difficult and often restricted spatially. At the center of conservation or reserve design is the FCA, or core area, which hosts most of the natural floral and faunal communities, and often retains the natural topography or other landmark features (TNC, 2004; Noss, 2003; Forman, 1995; Egbert et. al., 1999). However, a pandemic problem with FCA's is often the disheartening reality that they are too small, too isolated, or otherwise lack some functional quality vital for sound conservation (Davis & Schmidly, 1997; Callicott, 1996). The solution in these cases, which is a significant number of existing parks and reserves, is to either expand their borders or establish strong corridors between them and other natural areas. Expanding boundaries can be illustrated through the application of buffer areas surrounding the core FCA which might feature mixed land-uses or gradually expose the FCA to more intensive human use and presence (Noss et. al, 1997; Paquet et. al., 2001).

While expanding the boundaries may often be difficult for political and economic reasons establishing a buffer zone can bring attention to a reserves' susceptibility to change, influence, or degradation. It is also within these buffers where new acquisitions can become stepping stones to outward expansion or connectivity to a corridor. Corridors have gained attention for both wilderness areas and urban parks, such as the Greenbelts appearing in major metropolitan areas throughout the country. In a more ecological sense corridors function as migration routes for wildlife between protected habitats and nearby habitats, often unprotected islands of habitat dissected by urban development, resource extraction, or agriculture. These corridors can be vital to species survival, especially for large mammals in danger of automobile traffic, hunting, or other forms of mortal contact with humans. Corridors also allow for source populations to breed with outside populations, predators to follow prey herds, and for species to expand into new territories when they reach adulthood. For the purposes in this paper two types of corridors will be analyzed with respect to the major FCA's discussed: land-based and riparian corridors. Riparian corridors are more often protected than open landscape linkages due to difficulties leveling the landscape, or quite often for our need to protect water quality by maintaining natural vegetation in our watersheds. Open landscape linkages can be significantly more difficult to establish if the surrounding landscape is intensively developed or impacted, yet possess the potential for sound conservation of large mammals relying upon open space for survival. Many experts in reserve design, environmental science, geography, wildlife management, and other fields, believe the future of conservation may lie in the rural landscape functioning as a border between the most remote, wild areas and urban centers (Davis & Schmidly, 1997; Carr et. al., 2002).

A central purpose of reserve design is more specific than the conservation areas themselves, but often the key components are wildlife species. For conservation networks to be truly functional, for example, they must be capable of supporting and protecting keystone or umbrella species (Noss, 2003; Turner, 1997). With larger conservation networks in the Sierra Nevada, Florida Everglades, and Rocky Mountains ecosystems the key umbrella species are rightfully considered the top predators, such as bears, wolves, and mountain lions. Their key role in the food chain was historically discredited, often subject to hunting, predator control, poisoning, or extirpation from their natural region- one of the most tragic facts of large wildlife species today (Goodall & Bekoff, 2002). The fate of large predators nationwide has been fairly consistent as most have been pushed into remote wilderness areas or rugged terrain while smaller predators infiltrate these evacuated areas, such as coyotes and bobcats, a process known as mesopredator release. Thus, conservation efforts today are gradually beginning to focus upon umbrella species as an indicator of how successful a reserve functions. One of America's most noteworthy case studies began in the 1990's with the reintroduction of wolves into several Rocky Mountain states, and the sometimes mortal backlash from ranchers and farmers. The Defenders of Wildlife, local tribes, and the general public outcry helped continue the reintroduction efforts. In other regions megafauna have regained some of their status in the public's eye, such as seen with the mountain lion's silent and elusive presence in major California cities. Texas, however, has a long history of anti-predator sentiments and attitudes taking its toll upon North America's largest feline, including the mountain lion's current unprotected status throughout the state which even permits the killing of cubs and pregnant mothers throughout the year

(Goodall & Bekoff, 2002; TPWD, 2005; Clark, 1999; Sierra Club, 2005; Kramer, 2005). For instance, the effects of mesopredator release is evident throughout the study area with the proliferation of coyotes and bobcats to fill the niches left by mountain lions, bears, and wolves after two centuries of persecution. An equally disheartening example is the complete eradication of wild-roaming American Bison, once a dominant characteristic of the plains and prairies. However, the TPWD assures the public that mountain lion sightings are increasing throughout Texas, including the Cross Timbers and Blackland Prairie ecoregions assessed here (TPWD, 2005; TPWD, 1998). Other factors affecting wildlife populations throughout Texas are the privatization of wildlife- since most land, and essentially wildlife habitat, is privately owned,- introduction of exotic species, and land use systems adversely influencing wildlife management practices (Teer, 1999). In a stark contrast to large predators several game species have been brought back to stable numbers and reclaimed their former territories through active wildlife management, especially the white-tailed deer once again common in North Texas and the most widely distributed hooved animal in the United States. However, the success of white-tailed deer is largely determined by its game status and ability to generate revenue through hunting licenses, permits, and fees- resulting in substantial, accumulative contributions to the sporting tax fund which the TPWD depends upon.

Corridor connectivity and suitability can be addressed from multiple standpoints, from human-defined boundaries to actual use patterns by wildlife. One of the best indicators of a corridor's functionality, however, is a larger carnivore who will depend upon it for resources and movement between resources areas. Mountain Lions have been particularly useful as an indicator species for corridor design in urban-wildland interfaces due to their need for minimizing anthropogenic landscapes and features while favoring natural landscapes and features, in particular their sensitivity to development and habitat quality. Research in the Santa Ana Mountain Range may be the most informative for the purposes here, summarizing general characteristics of the mountain lion's selection of home ranges and resource areas based upon habitat composition, riparian habitats specifically, road density, distance from highways, and gentle slopes (Dickson et. al., 2005). Several of these factors will be used to test the proposed habitat corridors central to this paper following the application of regional and local landscape models. Moreover, the mountain lion's occasional presence and random sightings in Denton County clarifies its importance as an indicator species for conservation design in the county and North Texas region since it may be the only large predator capable of co-existing in a largely urban landscape (Bezanson, 2006; Smith, 2006; Coats, 2006). In addition, the aforementioned research shed light upon the functionality of highway underpasses or protected crossings for wildlife. Although mountain lions generally avoid highways they are forced to cross them to reach other resource areas (Dickson et. al., 2005; Dickson & Beier, 2002; Beier, 1995).

Whereas the regional model attempts to show potential connectivity, or the lack thereof, between existing conservation areas the local fine filter model emphasizes Denton County specifically. The two FCA's of interest were both created by lake impoundments yet became the largest geographical areas of protected habitat in the county. The initial Lake Ray Roberts State Park units were enjoined with the Ray Roberts Greenbelt to act as one functional conservation area while the Lewisville Lake Environmental Learning Area (LLELA) is considered the only other protected FCA in the county. Both would function as geographical anchors for the existing habitat mask used to create wildlife corridors and proposed conservation areas although there are inevitable questions regarding their connectivity and level of protection. Neither FCA was considered in the Texas GAP Analysis report nor Trans Texas Corridor EIS except for the state park units (Parker et. al., 2003; TX DOT, 2006). In-depth coverage of wildlife use and presence in Denton County and the Ray Roberts Greenbelt has been provided by the Institute of Applied Sciences (IAS) reports and past graduate students at the University of North Texas involved in ecosystemic and avian studies (see Barry, 2000; Hoffman, 2001). Both mammalian and avian species appear to be well represented based upon these data sources but could not be incorporated into the GIS suitability maps due to limited spatial coordinates for biodiversity census data. The IAS report in 1997 reveals 37 permanent avian residents, and several species of summer and winter residents. Common resident species included: screech owl, great horned owl, barred owl, long-eared owl, red-tailed hawk, red-shouldered hawk, and American kestrel (IAS, 1997). Red-tailed hawks showed the highest ecological density during the spring season at 8 individuals per 100 acres in bottomland forests, and 2 individuals/100 acres in shrub. Meanwhile, great blue heron were as high as 15 individuals/100 acres. Both the red-tailed hawk and great blue heron were included in this study to test their suitable range further.

The IAS Post-Impoundment Reports determined the ecological density per habitat type to show that bottomland forest, upland forest, shrub and pasture have the highest values at 1,800/100 ac, 1,446/100 ac, 1,376/100 ac, and 657/100 ac respectively (IAS, 1997). Meanwhile, mammalian use of the area was dominated primarily by generalist species: raccoon, striped skunk, coyote, armadillo, opossum, gray fox, eastern cottontail, bobcat, white-tailed deer, fox squirrel, and beaver. The bottomland habitat was identified as the most sensitive indicator of habitat quality since it had been heavily impacted by the Ray Roberts Impoundment and revealed only moderate mammalian diversity (IAS, 1997; Zimmerman, 2004). However, in comparison to the remaining portions of Denton County, the greenbelt may show the highest level of mammalian diversity and least amount of human impact given the influence of the impoundment (Barry, 2000).

Issues relevant to conservation of biogeographical resources and special elements of the landscape penultimately require a prescription following analysis. In effect, assessing the state of the land, habitat quality, species protection and the like will fall flat without strategies for implementation. For this purpose, then, the scope of conservation design relies upon sufficient planning from federal, state and local governments, land developers, and landowners. To meet this need various options are available from the acquisition of wilderness areas to the small-scale management of habitat on an individual parcel of land. As this paper explores geographical suitability for a conservation network through strict GIS methodology the research turns to options for land acquisition and management once suitable areas are identified. Since most of Texas is privately owned the more extreme option of large-scale land acquisition by a government body is most often unfeasible unless the geographical area possesses substantial ecological value. In the case of Denton County areas deemed suitable through Landscape Suitability Index (LSI) presented in the proceeding methodology section were then assessed according to different conservation planning and management options, depending upon the size of the area but also the number and variety of landowners involved. Acquisition and management options discussed below and for the final selection phase will be taken mostly from the Texas Parks and Wildlife's "Conservation Easements: A Guide for Texas Landowners" and the National Park Service's "Protecting Open Space: Tools and Techniques" (TPWD, 2003; NPS, 2004).

According to the NPS guide 11 conservation tools are commonly practiced, each one specific to the needs of landowners and conservationists. For full descriptions of these options and associated case studies please consult "Protecting Open Space: Tools and Techniques" for those details omitted here. In general protecting open space and habitat can have numerous benefits from protecting wildlife habitat, saving expenses for local governments on flood control measures, and offer tax incentives, increase property values whether its for the private parties, organizations or governmental entities (NPS, 2004). The first option of bargain sale of land is commonly known as a charitable sale, an agreement to sell land under federal tax codes to a non-profit or governmental agency under the market value. Tax benefits from a bargain sale include qualification for a charitable deduction or the opportunity to reduce capital gains tax. The second option falls under a more suitable conservation practice known as Parkland/Trail Dedication.

Park or trail dedications are often initiated by local governments which require subdivision developers or builders to dedicate land for conservation or to exact a fee for land acquisition. The area of land to be developed can be determined by a fixed area ratio, population density. or some other criteria. However, developers often challenge such exactions by local governments and ordinances while also acting as a deterrent to development. Option #3 is conservation zoning initiated by municipal governments to use overlay zones which may protect special resource areas in addition to ordinances already in place. Areas such as wetlands, floodplains, upland habitat, and historical cultural resources can be protected through such measures. One example of this is the creation of environmentally sensitive areas by the City of Denton (COD) in their Open Space master plan which focuses primarily upon riparian areas, scenic views and steep slopes (City of Denton, 2004). Trail easements are an additional option which grants use of corridors across properties less than the outright purchase of the property (NPS, 2004). Trail easements ultimately run with the land and are legally binding even if ownership of the land changes unless it is only for a fixed number of years. The Ray Roberts Greenbelt Trail, in fact, was created in part by trail easements for most of its northern boundaries as it intersects private and agricultural land, still quite visible when walking along the fencelines and seeing cattle adjacent to heavily forested areas occupied by wildlife within the park boundary. Such is proof of a multi-functional landscapes if both forms of land use are supported and regulating, but they may also fail if the landowners terms are too restrictive, their use of the land changes, or if trail management is too costly to the trail sponsor or government entity.

Option #5 is a conservation easement, a practice which offers permanent protection of the land while granting the landowner entitlement to its ownership. The landowner retains their right to choose the appropriate forms of land use, which is enforced by the land trust who adopts the easement. In addition, the conservation easement offers substantial financial benefits in reducing property taxes, income taxes, and estate taxes with the reduction of the land's market value. The purchase of development rights, or PDR, is the relinquishment of development rights to a governmental or private entity while allowing the landowner to retain overall ownership rights (NPS, 2004). This option has the noteworthy of advantage of enabling large-scale protection of wildlife habitat and open space for the purposes of this paper although PDR programs can be costly while landowners may have to continue paying high capital gains taxes. Option #7, transfer of development rights, might be more appropriate for protecting functional places than large resource areas with its encouragement of protecting unique, functional places while encouraging development in areas which are more suitable. Moreover, the limited development option resembles the transfer of development rights in that developing a portion of the landowner's property is part of the tool to conserve functional places.

Likewise, option #9, Conservation Subdivisions, promote dividing the landscape between conserved areas and developable areas accordingly, although such a technique can be fruitful for protecting micro-habitats, such as in the Chimney Rock subdivision in Flower Mound, Texas (NPS, 2004; TPWD, 2003). Zoning densities can be significantly reduced while encouraging open space as part of the subdivision, often as a common area. Nevertheless, this option still may include the loss of important habitat if the developer does not recognize its true importance and dedicate the appropriate natural resource for open space (NPS, 2004). Option #10, Deed Restrictions, places limits upon land uses on the property but can be handicapped by time limits and lack of enforcement. The final conservation tool is perhaps one of the more effective options available, a Wildlife Property Tax Valuation. In this scenario landowners may only have to pay taxes for the land's productive rather than market value if it is designated for agricultural purposes, wildlife management, or ecological research by academic institutions. However, the property must meet three of the following criteria to qualify in order to be designated for wildlife management: habitat control, erosion control, predator control, supplemental water supplies, supplemental food supplies, shelter, or for making population census counts. Moreover, a property may qualify for a Recreational, Park and Scenic Land Valuation if the parcel is less than five acres and the deed restriction is equal to or greater than 10 years.

Of the aforementioned conservation tools only a select set can be considered for improving the conservation of Denton County's ecological resources identified later in this paper following the LSI results: parkland/trail dedication, conservation zoning, trail easements, conservation easements, purchase of development rights, and wildlife property tax valuations, and finally recreational, park and scenic land valuation. Of the 11 options identified by the NPS guide these appear to be the most suitable and effective means of either acquiring or managing functional landscapes, corridors, areas and places at the magnitude necessary and demanded by the scope of this research. Each proposed functional conservation area, functional place and corridor will ultimately require different means of protecting the land and options to work with private landowners. Moreover, some instances may require the lesser options mentioned previously on spatially significant properties where the primary conservation tools are not practical. Nevertheless, the most preferred option for large-scale acquisition and management of functional space and places is through park dedications and conservation easements due to their long-term effectiveness.

Alternatives to these conservation tools exist at the state and federal level, specifically through the Farm Bill provisions of 2002 and carried out by the Natural Resources Conservation Service (NRCS). Programs of interest to landowners include:

Conservation of Private Grazing Land, Conservation Reserve Program (CRP), Conservation Security Program, Continuous Conservation Reserve Program, Environmental Quality Incentive Program, The Farm and Ranch Lands Protection Program, Forestland Enhancement Program, Grasslands Reserve Program, Wetlands Reserve Program, and the Wildlife Habitat Incentive Program (TPWD, 2006). Any of these options may be available to the landowner although limitations or caps per county and acres are not uncommon. Nevertheless, the NRCS will often compensate landowners for the majority of the costs when implementing natural vegetation and wildlife habitat. In 2003 seventy-six conservation easements were in place protecting 51,074 acres throughout Texas in the Wetlands Reserve Program alone, a program with an eight million dollar budget per the Farm Bill of 2002 (TPWD, 2003; TPWD, 2006). As of 2006 over four million acres of Texas land is registered in the CRP although no records of land in Denton County could be found (TPWD, 2006). If landowners in the affected areas can be educated of the different conservation tools and programs, the land trust agencies willing to participate in them, and of their land's ecological significance, the conservation network proposed may reach actualization. Without such participation and willingness, however, functional spaces and places may imminently remain disparate and fragmented until they are protected. Hopefully, by the end of this paper there will be a guiding optimism which leads the final stage of solutions.

Moreover, resolving the issues of disappearing open space and habitat fragmentation may require more than individual land management strategies on the one hand, and large scale state and federal programs on the other. Effective planning at the municipal, county and regional level may possibly offer the most efficient and effective means to regulate growth. Different solutions offered include: channeling new development into existing urban and suburban areas rather than encroaching upon natural areas (1), encouraging more compact development (2), concrete delineation of natural areas and declaration to protect them through municipal regulations, zoning and master plans (3), and to establish Urban Growth Boundaries and Urban Service Boundaries (4) consistent with the aforementioned principles (Ewing & Kostyask, 2006). In Denton County these solutions would entail a comprehensive regional body, such as the North Central Texas Council of Governments (NCTCOG), Denton County, and all municipalities affected. For instance, the NCTCOG could delineate a high priority conservation area within the county that would encourage if not enable the County to implement similar measures for each municipality to act in accordance with, especially those whose city and extraterritorial boundaries intersect high priority areas. However, regional bodies often have circumvented influence over local land use plans which is a similar obstacle at the County level, a situation which leaves municipalities as overwhelmingly responsible for developing strong land use policies, inventories of natural open space, and implementing comprehensive compliance programs (Ewing & Kostyack, 2006). In the study area of this paper only land outside of city and extraterritorial boundaries are considered the jurisdiction of Denton County, for example, which means only a small section of the county can legally fall under a comprehensive conservation plan. For that purpose exclusively the conservation assessment and proposed network which follows in proceeding sections emphasizes the rural landscape as the quintessential unit of analysis- geographical space which remains unincorporated and thereby not subject to municipal land use plans. At the same time, however, Denton

County lacks a county-wide inventory of natural habitat, open space, and wildlife, and similarly lacks an office or intrasite agency responsible for such endeavors. Effective conservation planning will thus require amendments to the existing political structures of the entities involved, and perhaps provoke changes in state legislation and support.

CHAPTER III

STUDY AREA

Conservation in North Texas will be assessed primarily for Denton County except for the initial regional assessment of the eight adjacent counties occupying both the Cross Timbers and Prairies, and the Blackland Prairie ecoregions. The selection of these counties is merely to stress the principle of proximity and adjacency to the primary area for those conservation areas and corridors which cross county borders: Collin, Cooke, Grayson, Wise, Montague, Parker, Tarrant, and Dallas counties. Within the Cross Timbers and Prairies ecoregion the study area was divided into 3 distinctive ecological subregions: Western Cross Timbers, Grand Prairie, and Eastern Cross Timbers. Two additional ecological communities were included with bordering regions with the Mesquite forest and Oak Savanna west and east of the study area respectively. The study area's major cities include Dallas, Arlington, and Fort Worth with numerous mid-level cities comprising the surrounding landscape. North Texas is a dynamic ecological and climatological region with variable rainfall, temperature, vegetation, species, and other characteristics. It was also the center of early American history as a pioneer region with traces of the earliest settlements still visible. In addition, prehistoric settlements can be found throughout the study area. Of the nine counties assessed both Tarrant and Dallas Counties possess the highest population figures with Dallas-Fort Worth spanning both counties. Meanwhile, population in Denton County continues to climb as the City of Denton recently surpassed 100,000 and other cities in the county continue to show signs of growth. As of 2007, population estimates for Denton County have reached 578,500 with a 3.27% growth rate from 2005-2006 (NCTCOG, 2006). Rather than emphasize population statistics emphasis was given to city jurisdictional boundaries, existing habitat, FCA's, and the rural landscape within the study area. Surprisingly, the presence of numerous wildlife species and remnant natural habitat in the study area is still abundant.

Denton County's primary conservation areas are the Ray Roberts State Park and associated Greenbelt (RRSP) and Lewisville Lake Environmental Learning Area (LLELA). All other natural areas are either unprotected or are subject to municipal open space planning and zoning considerations. The major regional FCA's in the immediate vicinity of Denton County are two state parks, one National Grassland, and one National Wildlife Refuge: Lake Mineral Wells State Park (LMWSP), Cedar Hill State Park (CHSP) in Dallas County, Lyndon B. Johnson National Grasslands (LBJ) in Wise County, and the Hagerman National Wildlife Refuge (HNWR) in Grayson County. Each FCA possesses a distinctive ecological quality deemed significant for lamenting the design of a conservation network. Each has its own unique size, management strategies, threats, vegetation, wildlife species richness and composition, and landscape characteristics which can contribute to the aims of this paper, and more importantly, to the general cause of conserving the natural resources and wildlife of North Texas. HNWR, RRSP, and CHSP have all been considered valuable FCA's for migratory and native birds, many of which are either threatened or endangered, including the federally threatened Golden-Cheeked Warbler (Hill, 2005; TPWD, 2005). Several important species inhabit the region, including the following: Bald Eagle, Mountain Lion, Bobcat, Porcupine, Fox Squirrel, White-Tail Deer, Gray Fox, Porcupine, Northern Bobwhite, Eastern Cottontail, Great Blue Heron, Red-Tailed Hawk, Carolina Chickadee, and the

Golden-Cheeked Warbler (Davis & Schmidly, 1997; TPWD, 2005; Parker et. al., 2003). Throughout the field work conducted for this research the following species were encountered in the two primary study areas.

Table 2: Major mammals found in Denton County.

Common Name	Scientific Name
Virginia Opossum	Didelphis virginiana
Nine-Banded Armadillo	Dasypus novemcinctus
Eastern Cottontail	Sylvilagus floridanus
Fox Squirrel	Sciurus niger
Beaver	Castor candaensis
Coyote	Canis latrans
Raccoon	Procyon lotor
Striped Skunk	Mephitis mephitis
Bobcat	Felis rufus
White-Tailed Deer	Odocoileus virginianus
Red Fox	Vulpes vulpes

Table 3: Common reptiles and amphibians documented at LLELA and found elsewhere in Denton County (LLELA, 2004).

Common Name	Scientific Name
Texas Spiny Lizard	Sceloporus olivaceus
Ground Skink	Scincella lateralis
Common Snapping Turtle	Chelydra serpentine
Red-eared Turtle	Trachemys scripta elegans
Diamondback Water Snake	Nerodia rhombifer
Southern Copperhead	Agkistrodon contortrix
Small-mouthed salamander	Ambystoma texana
Western Lesser Siren	Siren intermedia nettingi
Green Treefrog	Hyla cinerea
Southern Leopard Frog	Rana utricularia
Gulf Coast Toad	Bufo valliceps

Figure 2: Denton County's major cities and existing conservation areas.

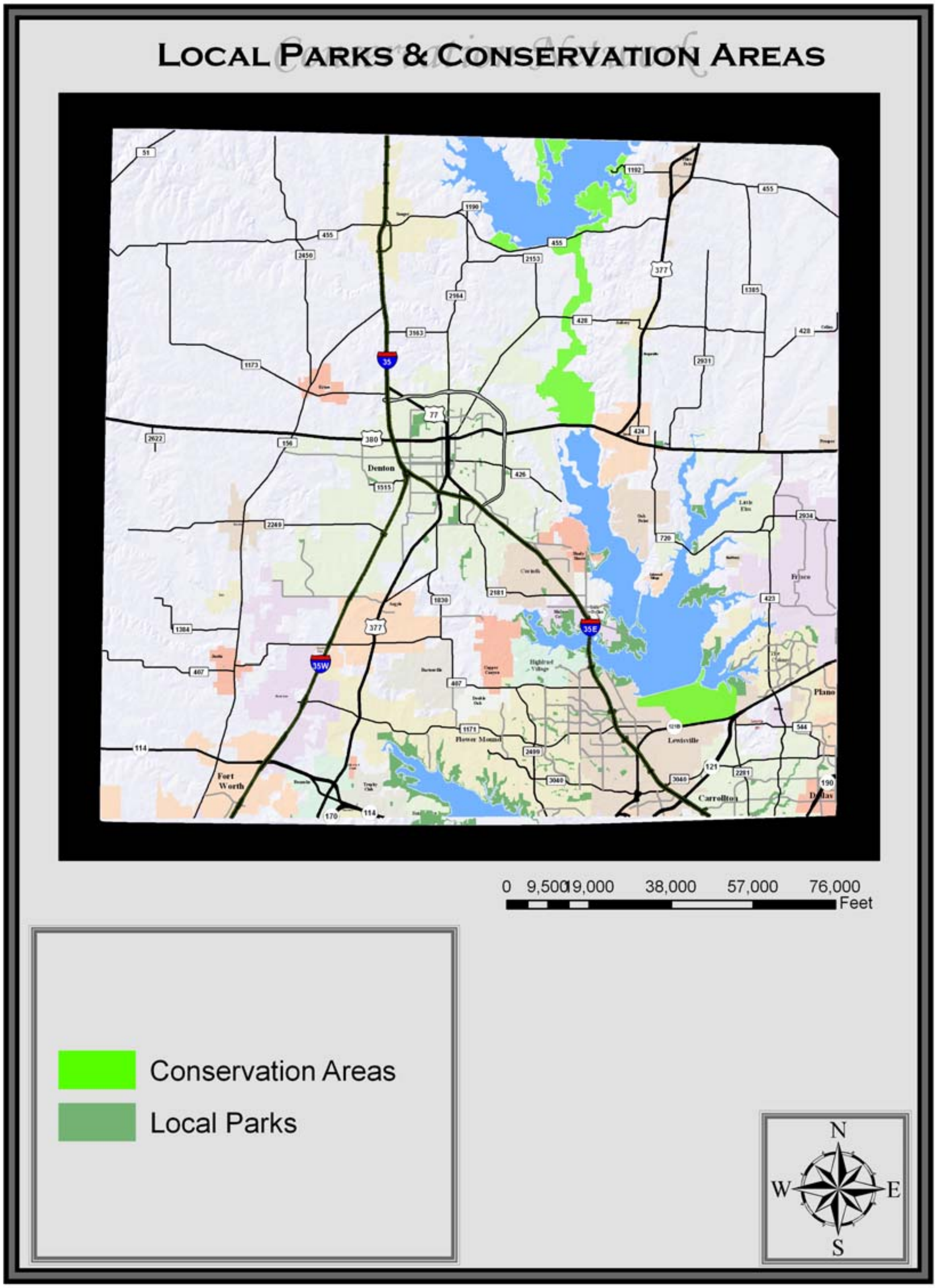
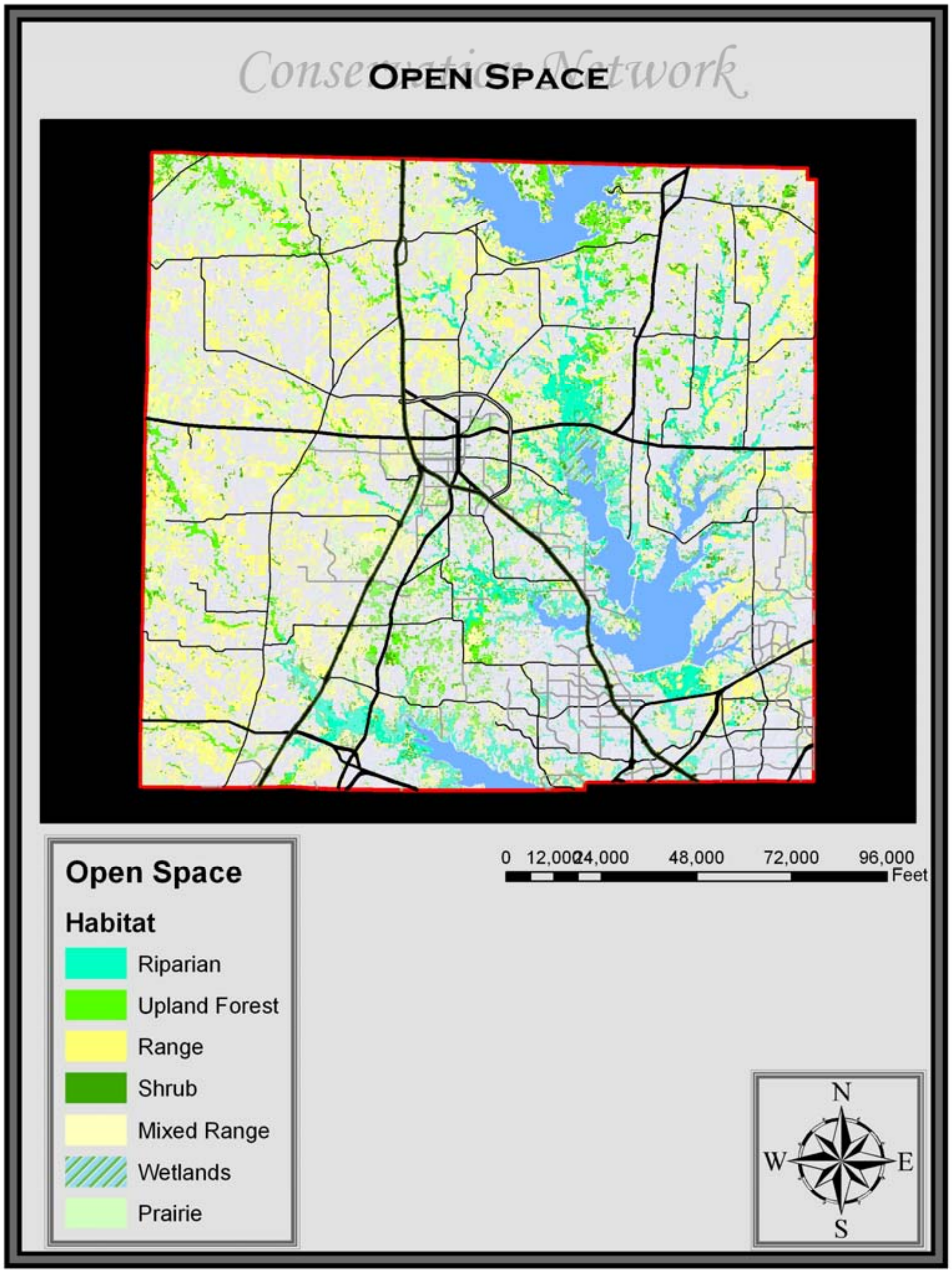


Figure 3: Depiction of natural areas and open space remaining in Denton County.

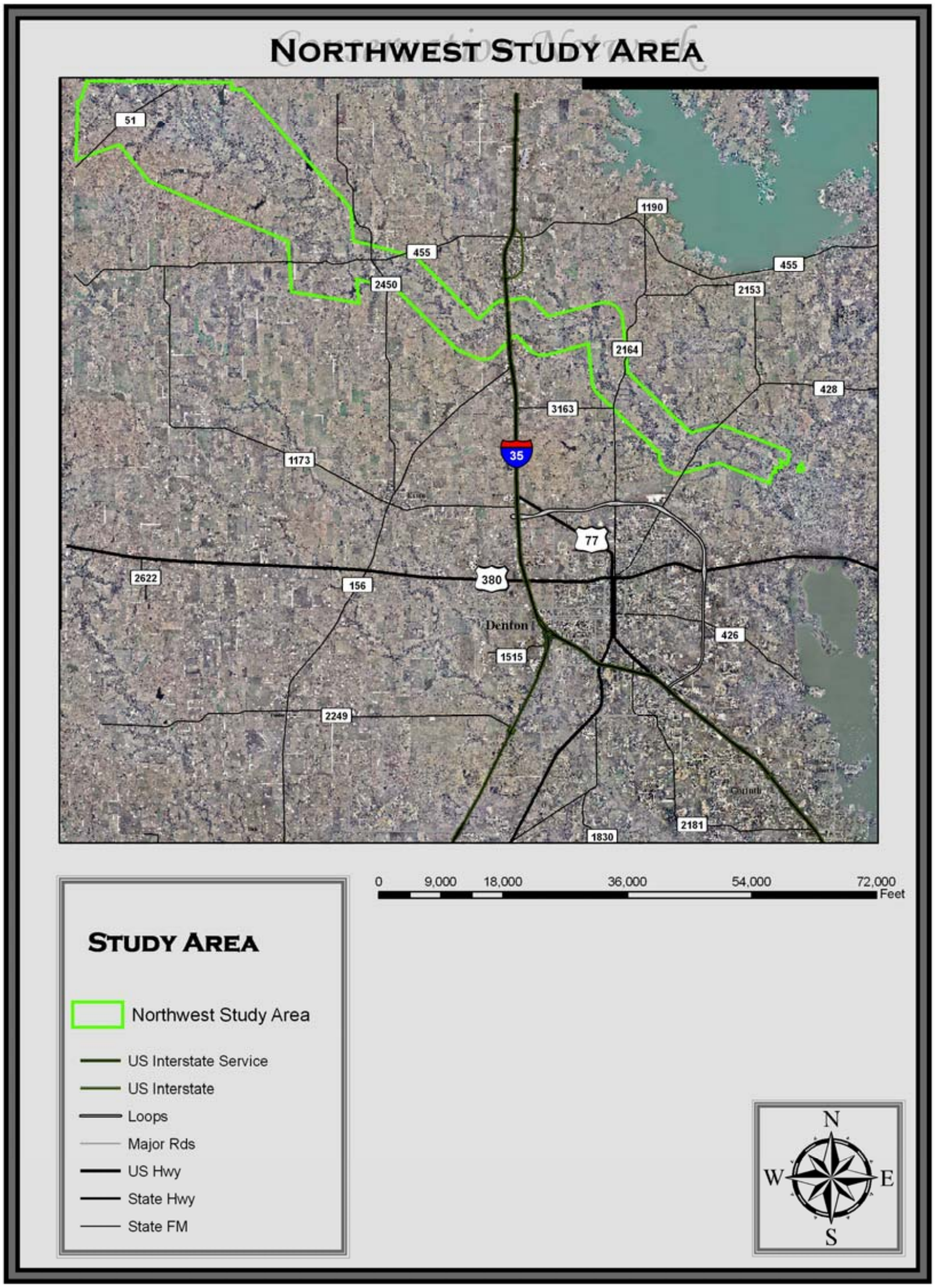


Unlike the regional model results for the local county-wide model relied upon the combination of land cover and 2005 aerial photograph to create a forest-habitat mask which was to become the basis for analysis. Two conservation target areas and two habitat corridors were created exclusively from geographical areas of relatively contiguous forested habitat. Conservation area 1 along the upper reaches of Clear Creek is the only geographical area not subject to jurisdictional boundaries with competing cities while conservation area 2 fell into areas of mixed jurisdictions- either as actual city boundaries or intersected by extraterritorial jurisdictional boundaries (ETJ). Additional maps of site-specific factors for each FCA can be found in Appendix A.

Conservation area 1 is located in the northwestern section of Denton County along the heavily forested upper branch of Clear Creek reaching eastward thru Sanger and towards the Ray Roberts Greenbelt. The elevation of this area ranges from 688 feet to 980 feet with some areas surpassing 1000 feet in the immediate vicinity. Landownership in the area includes 386 land owners, of which 224 individual parcels were appraised by the Denton Central Appraisal District (DCAD) at $28,598,362 (Crowe, 2007). 3,035 of the total 14,110 acres are identified as natural habitat- water, forest, shrub or wetland. 15.39% of the area is the forested area along Clear Creek and would later become the primary area for site selection following application of the County LSI. Water comprises 185 acres, shrub nearly 650 acres, and wetlands at 32 acres. A major portion of this area, however, is agricultural with approximately 4,100 acres designated as either crop or transitional crop and 6,900 acres as range or mixed range- approximately 50% of the total area surrounding the eventual conservation area. The habitat corridor connecting to conservation area 1 was named the Northwest Corridor and follows 26.41

miles of the historically and ecologically significant clear creek from the conservation area down through the Ray Roberts Greenbelt. The corridor crosses through the northwest county, Sanger and Denton from west to east. Furthermore, it is worth noting and cause of concern that gas well development may be highest in this region which will warrant careful planning and establishing ordinances on county land. However, area 1 was low for road density, subdivision and development permit densities which was responsible for the overall low composite index. Six development permits are located within the boundaries, with clusters of two permits in the northwestern (near FM 51), central and southeastern (near FM 455) sections. Parcel data shows that most of area 1 is classified as improved pasture, native grassland, and a mixture of cropland II, Cropland III, Undetermined. Interestingly, however, forested areas were not classified as neither timber nor woodland but as undetermined or native grassland-which brings doubt into the accuracy of the land type attribute data from the DCAD parcel layer and of its usefulness for the development and landscape suitability indexes. From an ecological standpoint conservation area 1 appears to be one of the most diverse, intact and possibly beholds the greatest potential for the proposed conservation network. Most of the soil types of this area are gravelly clay loam or fine sandy loam with pockets of clay and silty clay loams in portions of the northern and eastern sections, and a few pockets of stony clay and water. The reclassified soil types show that most of this area was Grand Prairie habitat with a the northern sections predominantly riverine bottomland. The forested waterway seen today would have historically been surrounded by native prairie, which is mostly crop and pasture today but potentially restorable in the long-term.

Figure 4: Upper reaches of Clear Creek habitat referred to as FCA 1 and Northwest Corridor.

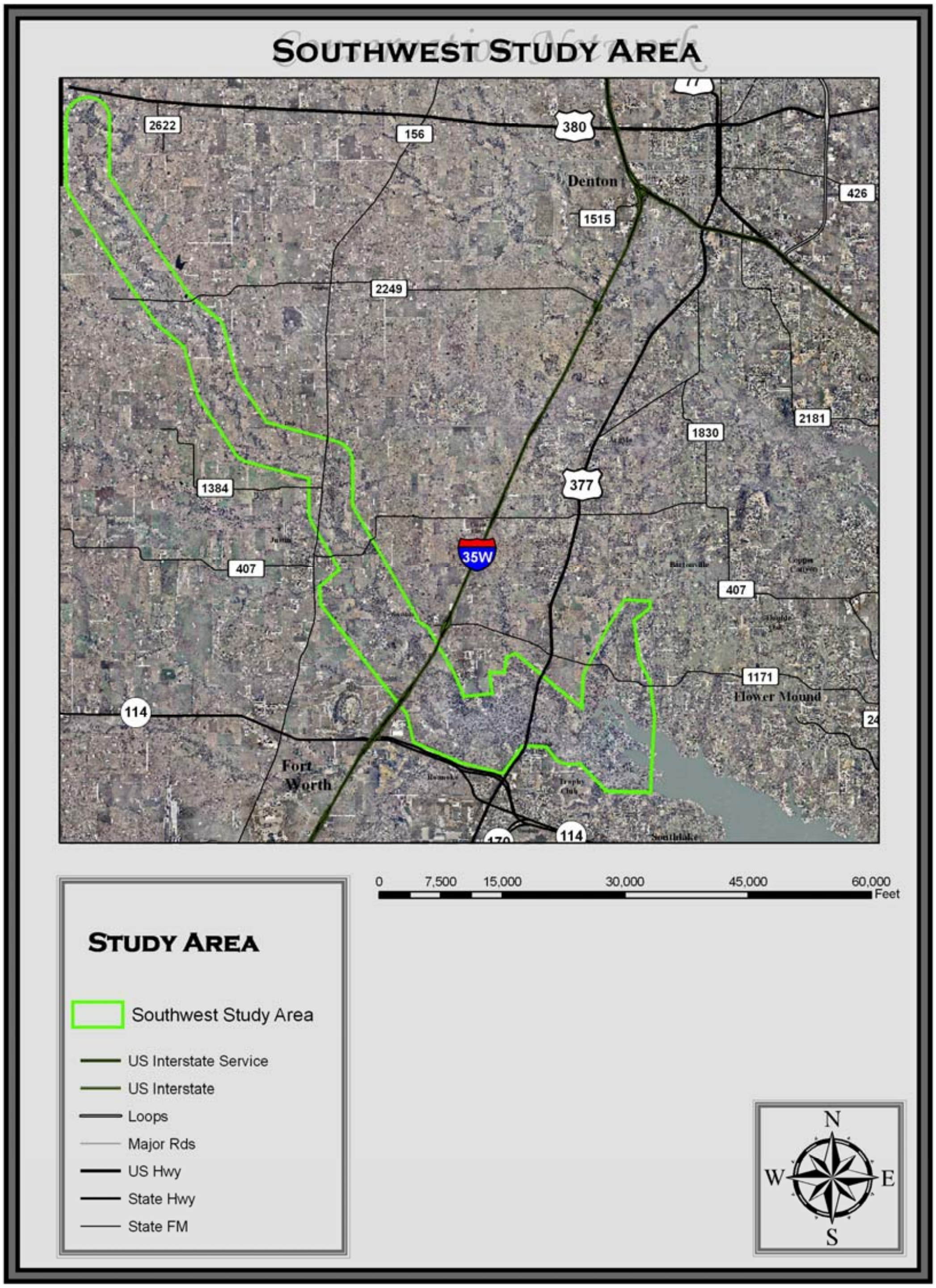


Land cover for area 1 shows a prominence of forested habitat bordering clear creek surrounded by herbaceous range, crop, mixed range, transitional crop, barren ground, and either ponds or wetlands. The strongest connectivity for conservation area 1 lays in its contiguous forested area which offers a certain level of protected migration while semi-managed pasture surrounding the area might prove auspicious for wildlife migration except without adequate protection. Use of the area by wildlife seems to be indicative of its functionality with the species richness composite of the 13 indicator species showing mid-range values for most of the area- from 0 in two pockets to 6 in the central interior with pockets of 7 dotting the landscape. Most importantly, conservation area 1 and the Northwestern-Central habitat corridor intersect the primary indicator species of this paper, the mountain lion, with overlapping boundaries along covering most of the target area. It is assumed from the Texas GAP species occurrence models that mountain lion distribution is heaviest along the western region of the North Texas study area and encroaches upon the interior at the boundary of Denton County and both counties north and south of it. Furthermore, the Northwest Corridor contains large sections of habitat with species richness values in the intermediate to high range with only marginal pockets of values below 2. In addition, the western third of the corridor overlaps the mountain lion range. Similarly, conservation area 2 partially meets this requirement.

Conservation area 2 is located in the southwestern region of Denton County and intersects several municipal boundaries: Northlake, Flower Mound, Roanoke, Marshall Creek and Trophy Club. Part of the eastern section is zoned as the Cross Timbers Conservation District by the City of Flower Mound and one of the more scenic drives in the county. Its associated corridor, the Southwestern Habitat Corridor, follows 21.42 miles of the historically and ecologically significant Denton Creek from the western county boundary east to Flower Mound. This area was populated by indigenous tribes during the pioneer movement and one of the primary trails used by tribes, military, and settlers. Furthermore, it was a resource-rich area for cultures relying upon natural resources offered by the mixture of forest, riverine and prairie habitats. Landownership in FCA 2 includes 662 land owners appraised at $78,155,191 with an adjacent parcel owned by the Texas Motor Speedway appraised at $34,121,389 (Crowe, 2007). The area is potentially the largest intact contiguous forested area currently unprotected and proposed for the conservation network. Nearly 4,500 acres of habitat was classified per the CSAM land cover with an additional 397 acres of water, 11 acres of shrub, and 254.15 acres of wetlands totaling 52% of the total area as natural habitat. However, it also subject to a high degree of pressure from development and competing land use agendas by neighboring municipalities. The overall development index values were low for the entire area with values ranging from 0 to 3 with the most significant factors coming from gas wells and road densities. Both the western and eastern sections of the area are subject to accumulative gas well development operations while most of the central interior is not subject at the time of this writing. Parcel data shows that most of the area was undetermined while clearly falling within the timber and woodland land types, with large sections of improved pasture, pasture, Cropland II, and native pasture with some pockets of commercial and residential lots interlaced with the landscape. Once again, the undetermined land type category overlaps forested habitat and calls into question the utility of the parcel land type attribute for the index while also offering incentive to grant the undetermined category a high value for the landscape suitability index.

Biogeographical variables for conservation area 2 suggest a fairly diverse and viable ecosystem if adequately protected. The predominant soil type of area 2 is a pocket of contiguous silty clay with large sections of clay, clay loam, fine sandy loam, gravelly loam, and stony clay throughout the area. The reclassified soil habitat layer shows a mixture of Grand Prairie, Riverine Bottomland and Eastern Cross Timbers ecoregions offering the most diverse proposed conservation area of the study. Furthermore, species richness values were highest in this area, with peak values of 9 in the eastern section while falling to as low as 3 in the northwestern section. Unfortunately, however, this area is also dissected by I-35 W while bordered by other major roads. Nevertheless, the central and eastern sections offer definitive potential as habitat and suitable wildlife range. The eastern section bordering Grapevine Lake in particular is suitable for the Bald Eagle and Great Blue Heron included in the 13 indicator species. Furthermore, the western boundary of conservation area 2 is in close proximity to the eastern extension of the mountain lion range whereas the Southwestern Habitat Corridor directly intersects it. Overall, species richness values range from 2 to 9 along the corridor with peak values along the northern section of unincorporated Denton County and at the eastern tip of the corridor.

Figure 5: FCA 2 demarcated by Denton Creek watershed and Grapevine Lake. Southwest Corridor stems primarily from this delicate riparian habitat.



CHAPTER IV

METHODOLOGY

A primary analytical tool of this paper is GIS due to its appeal to multiple applications and ability to improve decision-making processes, in this case for devising conservation strategies at the ecoregion level. GIS enables mapping the spatial extent of habitat destruction, conversion and other invasive anthropogenic forms of change (Pereira et al., 2004; Millennium Ecosystem Assessment, 2003; Allen and Hoekstra, 1992). The theoretical basis for this study was built upon international conservation values, environmental planning, and conservation biology principles in the search for ideal habitat from a geographical and philosophical perspective. In particular, conservation themes promoted by the Convention on Biological Diversity and Millennium Ecosystem Assessment, such as the ecosystem approach, are a major thrust for the topic of environmental protection and ecological sustainability (MEA, 2003; Allen and Hoekstra, 1992; Naess, 1998). Also relevant to this study are the philosophical underpinnings of environmental planning and protection, which led to the origination of this paper: recognizing the intrinsic value of ecosystems as motivation for protection advocated by biocentric and ecocentric approaches (Naess, 1998; Holmes, 1998; Gunter & Oelschlaeger, 1997; MEA, 2003). A major intellectual and methodological thrust underpinning this model was inspired by a prominent conservation biologist, Reed Noss, behind the wilderness reserve design networks in the Pacific Northwest, Florida, and around the country. Noss identified the primacy of identifying threat indicators to ecosystem integrity, habitat connectivity, special biological and ecological elements, and size itself, to formulate successful reserve designs for large wildlife species and restoration efforts (Noss et al., 1997; Noss, 1998; Noss, 2003). The utility of using GIS was inspired primarily by the need for establishing tangible values and threats, mapping them, and a systemic approach to applied environmental problems (MEA, 2003). Other examples of GIS applications for conservation are environmental monitoring, biodiversity reserve analysis, hierarchy of conservation sites, and wolf habitat models (Gily, 1985; Stoms et al., 2000; Miller et al., 2003; Milandoff et al., 1999; Noss et al., 1997).

Data provided from remote sensing and the Texas GAP project was fundamental to the regional model and deserves some clarification here. The utility and function of remote sensing to be discussed here primarily refers to an integrated analysis of ecosystem extent, the degree of environmental protection, and wildlife distribution in what has become commonly known as the GAP project (Parker et.al., 2003). Fundamental to GAP goals and methodology is the extraction of land cover information for the entire United States, and individually by state. As of the writing of this paper only a few state projects remain incomplete whereas most of the U.S. now has a common classification for ecosystems at the formation and association levels while numerous mammal, amphibian, and avian species are depicted based upon predicted range or occurrence. The process for applying remote sensing technology to GAP analysis may be divided into three components for a matter of convenience: remote sensing satellites and spectral resolution, land cover classification, and application to conservation.

With the national and state GAP projects preference has been given to Landsat Thematic Mapper (TM) as the ideal sensor balancing local, regional and global detection of environmental conditions (Scott et. al., 1993). Landsat TM sensors are ideal for delineating homogenous patches, vegetation properties, tree height, Leaf Area Index (LAI), spectral mixture analysis, canopy reflectance, and forest composition among other applications (Kasischke et. al., 2004). The most important goal of GAP analysis, however, is land cover delineation at the local, state and national levels which Landsat TM is well-suited for. Thus, delineation of forest structure, canopy cover, crown size, biomass and age are useful indicators of different land cover types with the most applicable information for GAP being depicting land cover at the association level (Kasischke et. al., 2004).

Land cover classification is the process in which raw remote sensing data is transformed into a common system or scheme of names for habitat associations and formations. A variety of classification schemes exist although many agencies strive for a common system, or at least one that can be readily transferred into another, such as with the National Vegetation Classification System (NVCS) or Anderson's scheme developed in 1976. Land cover classification falls into one of two categories: unsupervised and supervised. Unsupervised classification commonly includes cluster analysis with emphasis given to spectral and land cover classes whereas supervised classification commonly includes discriminate analysis and pattern recognition (Scott et. al., 1993). For example, the Texas GAP project utilized training sites and their spectral signatures for supervised classification while analyzing groups of pixels delineated by spectral values for unsupervised classification (Parker et. al., 2003). The unsupervised method employs a hyperclustering procedure or analysis discriminating spectral signatures across all seven Landsat spectral bands then labels the data per ancillary information and expert opinion. The Texas GAP project compressed groups into one band with mean values per pixel as the final product prior to classification at the association or alliance level with approximately 240 clusters (Parker et. al., 2003; Gonzalez-Rebeles et. al., 2003). Similarly the NVCS land cover classification for National Parks resulted with 255 clusters in analysis of three South Dakota parks (Smith et. al., 2005). The most important point to be made in land cover classification is the ability to group areas of common spectral signatures or properties in distinct regions for analysis, or into major life zones or subregions defined by spectral characteristics (Manis et. al., 2005). When defined at the pixel level for Landsat TM a 30 meter resolution results in 900 square meters, or the equivalent of 0.09 hectare patches (Smith et. al., 2005). With this in mind large areas can be classified relatively easy compared to historical methods of identifying and mapping vegetation types.

Once spectral signatures and categories are classified the information will evolve beyond the scope of remote sensing specialists into the hands and minds of a variety of environmental professionals. The final product for land cover mapping will be specific habitat types, such as forest, agricultural, grassland, water and urban areas with a range of uses analytically. In a case studies of detecting urban land cover types and change researchers focused upon delineating urban, suburban and rural land cover types at the association level mentioned above (Yuan et. al., 2005). In contrast the Texas GAP project concluded with over 63 land cover types defined at the alliance level, such as temperate round crowned-deciduous forest, riparian woodland, medium bunch temperate grassland, etc. (Parker et. al., 2003). Verification of the actual land cover including a variety of techniques, most notably field surveys, topographical maps, ground control points and other forms of ancillary information (Gonzalez-Rebeles et. al., 2003). Sampling sites for the Texas GAP project included two distinguishable types to provide an example of the complexity inherent to ground-truthing and classification in general: large homogenous patches with predominant species, and large heterogeneous patches with a mixture of species (Parker et. al., 2003). In fact, the verification process may be on-going and continuously refined until an accurate system is produced.

The final stage of GAP analysis is aimed specifically towards improving conservation and environmental mapping, decision-making for habitat and wildlife management, and even reserve network designs (Stoms et. al., 2005). Conservation Biology can be said to spearhead the GAP project both theoretically and as an applied discipline for the field of conservation (Noss & Cooperrider, 1994). GAP analysis ultimately provides for a biogeographical lense in which remote sensing and GIS play a fundamental role. In addition to land cover types species occurrence is considered a fundamental component and benefit of GAP analysis. Determining the predicted range of various species occurs after successful land cover delineation and is fueled by expert opinion and known species ranges (Noss & Coopernder, 1994; Parker et. al., 2003). In contrast to the GAP projects and the emphasis upon indirect wildlife mapping (e.g. inference based upon land cover types) wildlife distribution may also be depicted directly per individual species (Laurent et. al., 2005). In this case spectral properties of known habitats and species occurrences are the basis for spectral classes. With GAP analysis the final product for predicted occurrence is conveniently classified into either presence or absence of the species (Laurent et. al., 2005; Parker et. al., 2003). This simplification allows for a rapid assessment of potential wildlife habitat and probable occurrence of a species which may or may not be verifiable in the field. In the case of the direct method local experts, including hunters, field guides, and wildlife biologists will need to take part in delineating areas of actual wildlife populations. The GAP projects aim to be optimistic in this regard but may not always be reliable indicators. For example, in a separate report relying upon Texas GAP data the range depicted for mountain lions was called into question by actual sightings of mountain lions, including at least one case in each county of the study area whereas the predicted occurrence was limited to only 1/3 of the study area. Thus, it is up to the researcher, and the purposes of the project, to verify the methodology of data and determine both its usefulness and limitations. As the last step of GAP analysis the combination of land cover types, natural reserves (National Parks, National Wildlife Refuges, State Parks, and private conservation areas), and predicted wildlife ranges are combined using GIS spatial analysis to depict the percentage of land cover types and range of species protected by the current natural reserves. This analysis may be used to recommend conservation strategies for the future, such a acquiring a reserve which captures underrepresented ecosystem types and wildlife habitats.

The methodology employed for analyzing the FCA's, functional landscapes and places, and habitat corridors combines vector and raster GIS data for separate scales and models in order to create the most accurate depiction of the regional and local landscape- specifically its functional and structural properties. GIS models were created at both regional and local scales in order to explore and assess the functional properties of geographical space and places. After the regional model was applied to the North Texas study area for a preliminary scoping of biogeographical and cultural factors the assessment turned to three local models, which would become the penultimate lense for designing a conservation network and carrying out the goals of this research. While the regional model is presented first it is important to mention that the local Landscape Suitability Index (LSI), Open Space LSI, and Mountain Lion Habitat Suitability Index (HSI) models presented after the regional LSI were the final authority of analyzing geographical space and places. Base layers for the regional model prior to processing included: major roads, land cover, parcels, tracts, state and municipal parks, reservoirs, urban centers and cities, wildlife distribution models, ecoregions and subregions, vegetation communities, major streams, census, county, landfills, superfund sites, and watersheds. Second stage processing includes advanced spatial analysis methods in order to create tangible landscape units for analysis: a rural landscape via erasing city boundaries from the nine county study area, creating a 300-foot stream buffer around major waterways, using raster calculator for a species richness and prey richness models, resampled and reclassified land cover, a union of vegetative communities with ecological subregions, and a union of FCA's. Land cover data was reclassified from its original habitat types, e.g. post oak-blackjack oak, temporarily flooded deciduous woodland, etc. into more tangible ecosystems types: forest, grassland, shrubland, savanna, water, crop, urban, and other (bare soil, sand flats).

Figure 6: GIS Flowchart for Regional LSI.

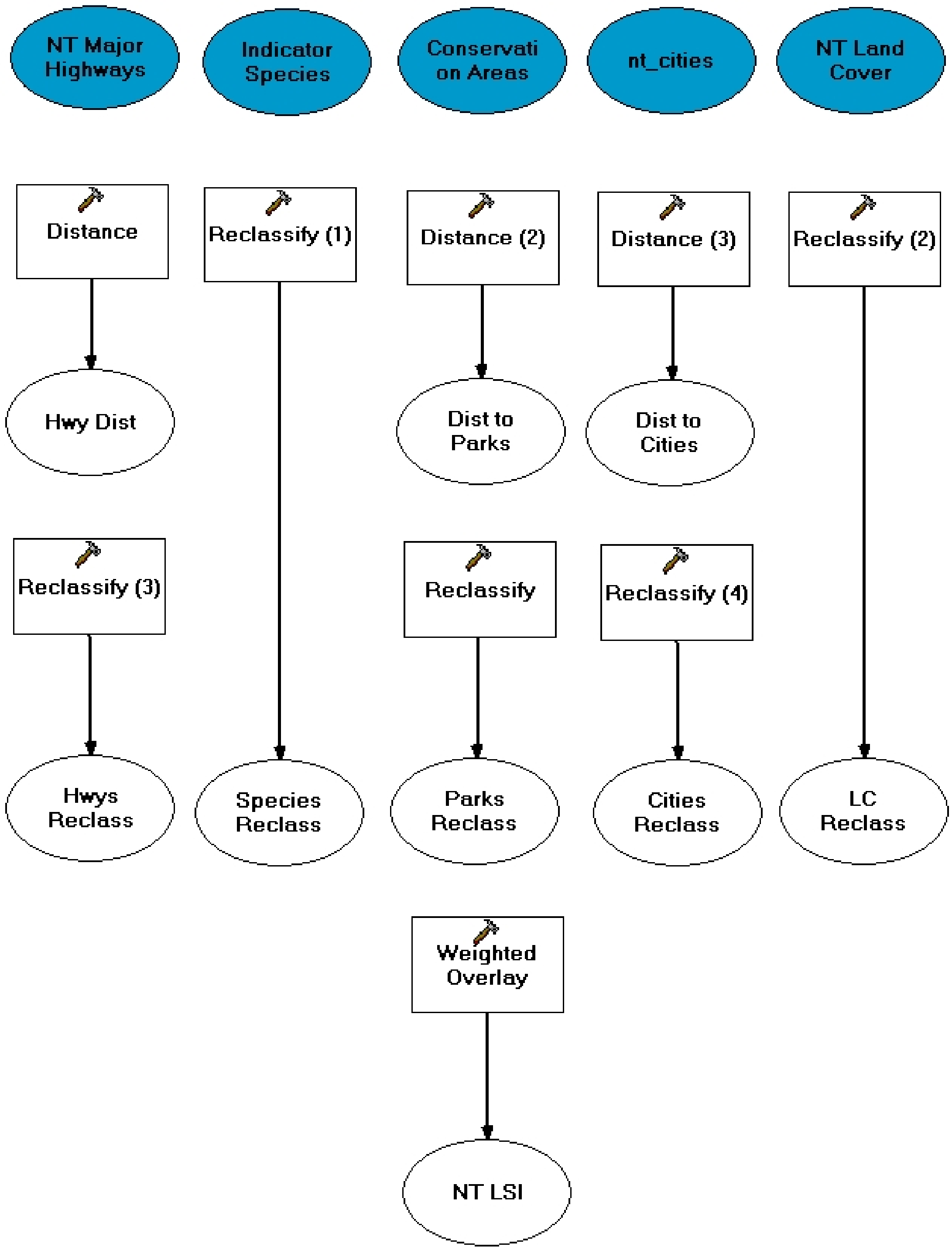


Figure 7: Land Cover recreated from National Land Cover Data Set for North Texas study area.

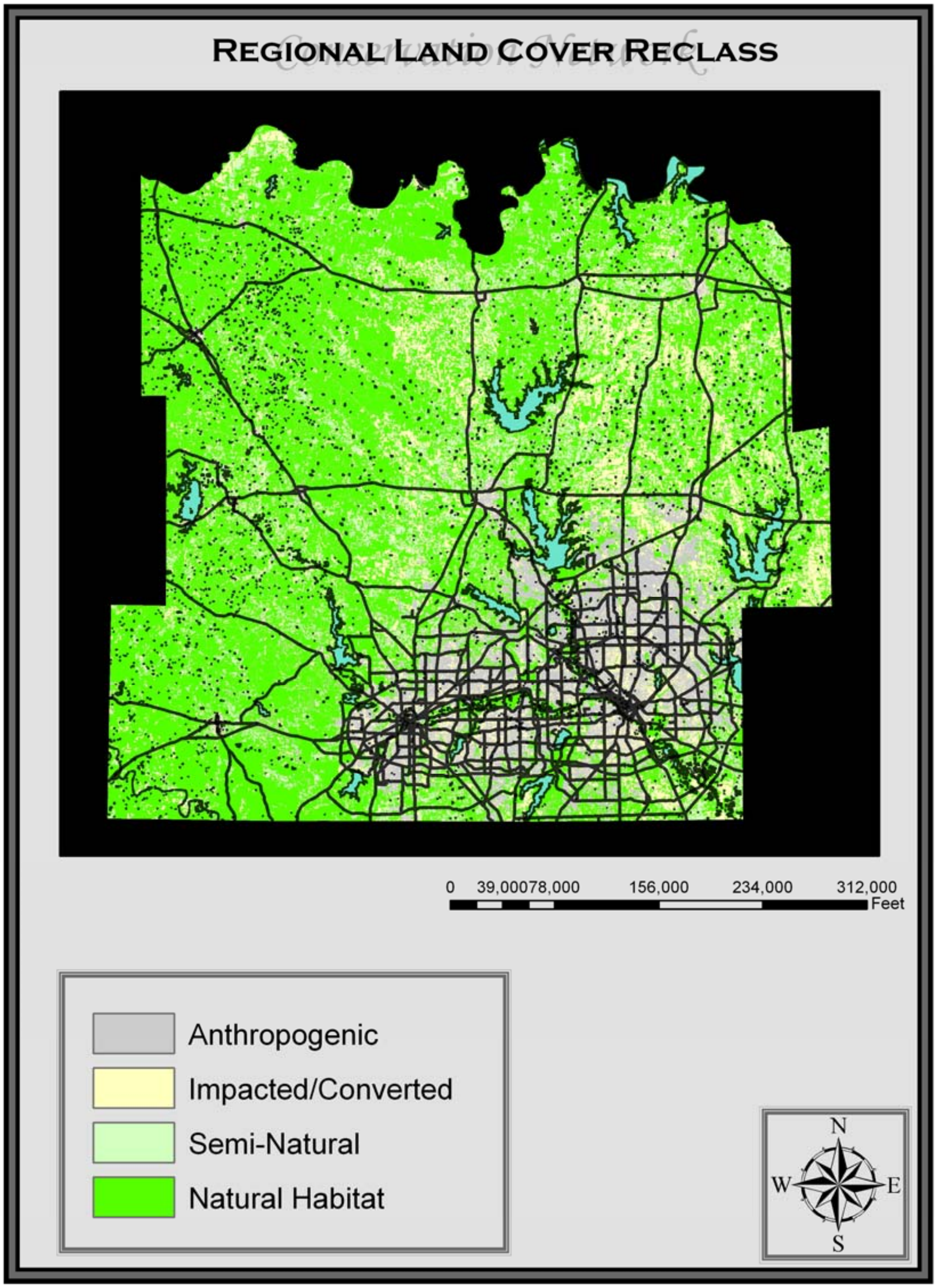


Figure 8: Indicator Species Distribution for North Texas.

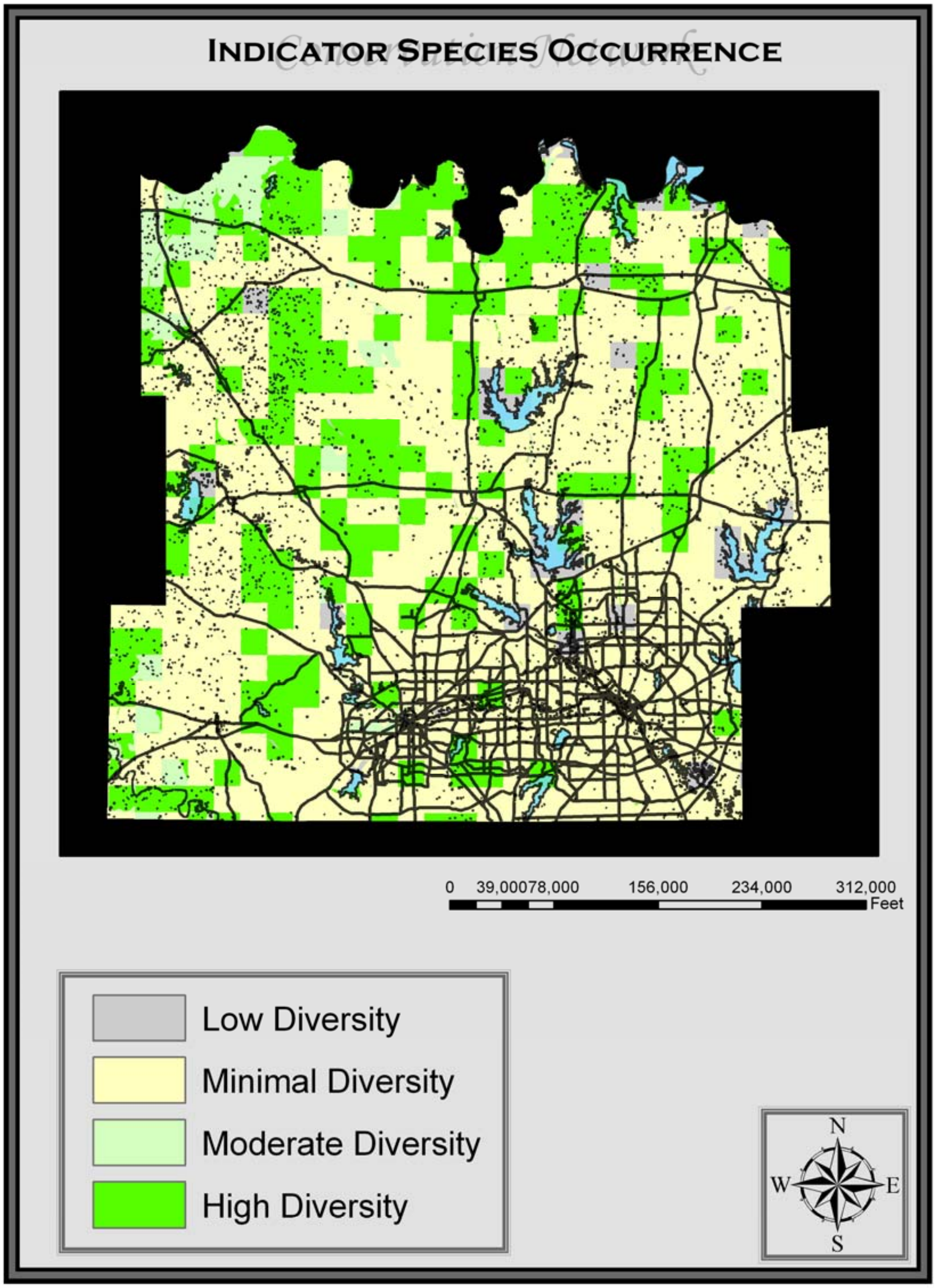


Figure 9: Distance from Major North Texas Cities.

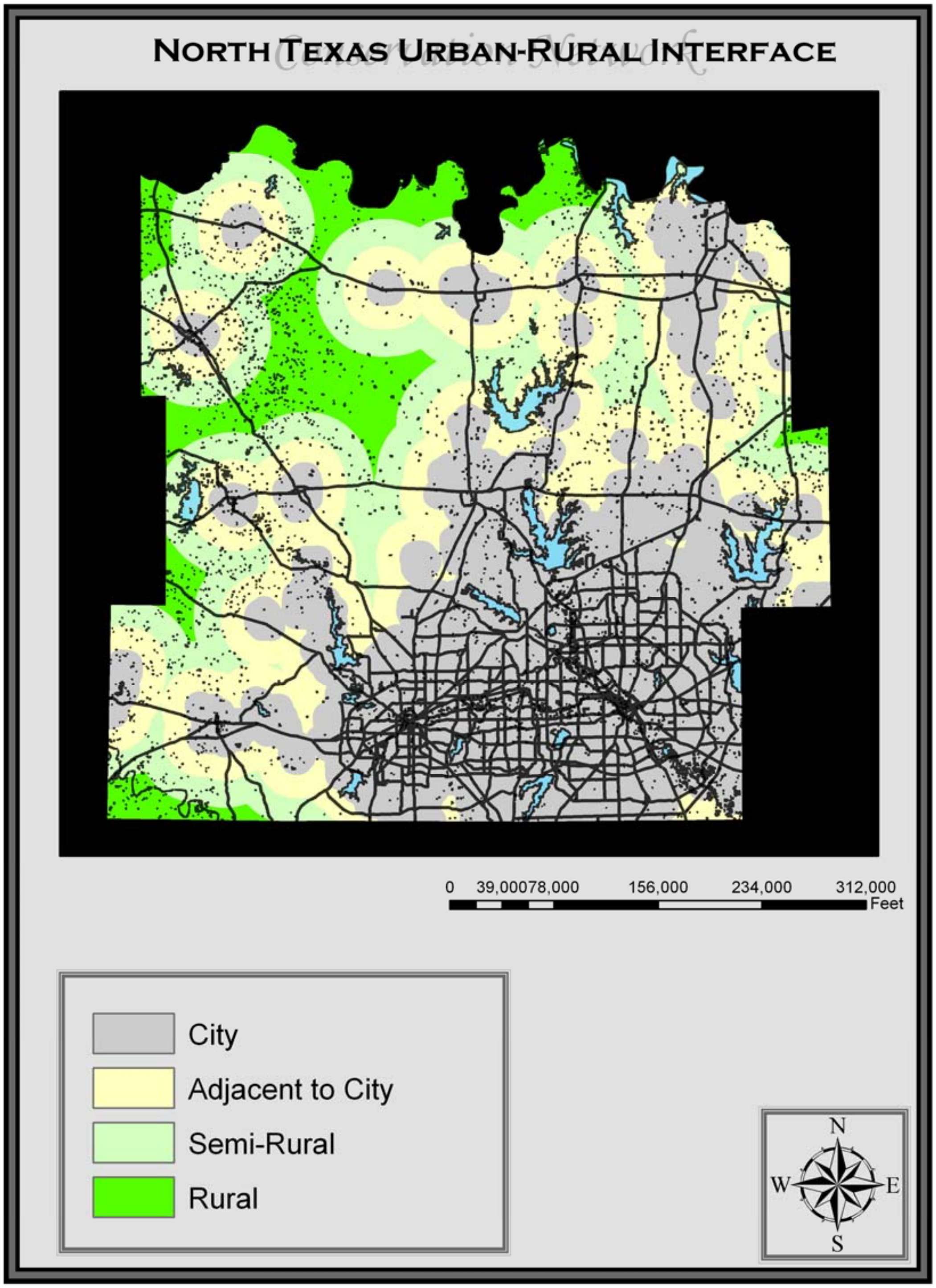


Figure 10: Distance to Major Conservation Areas in North Texas.

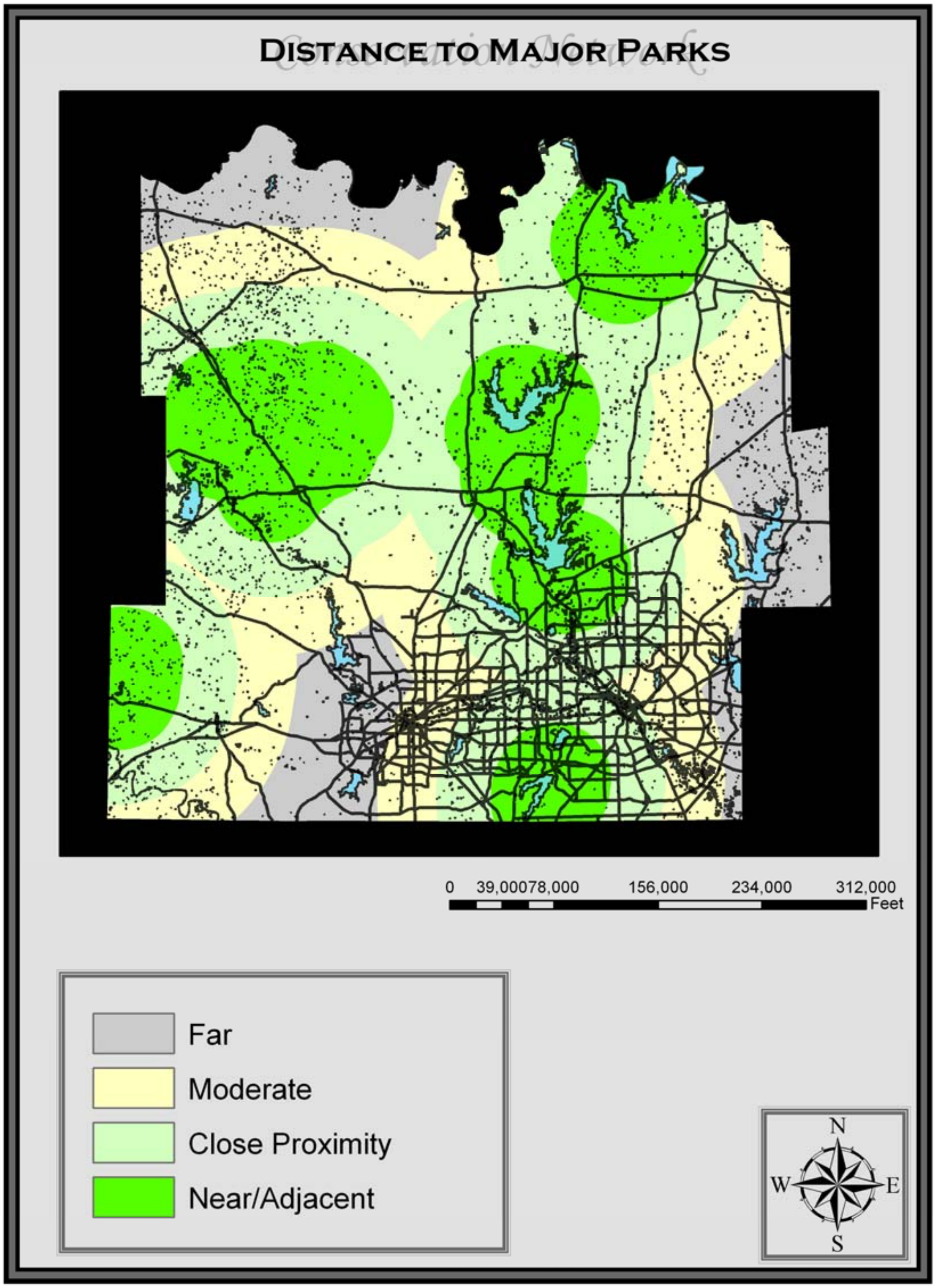
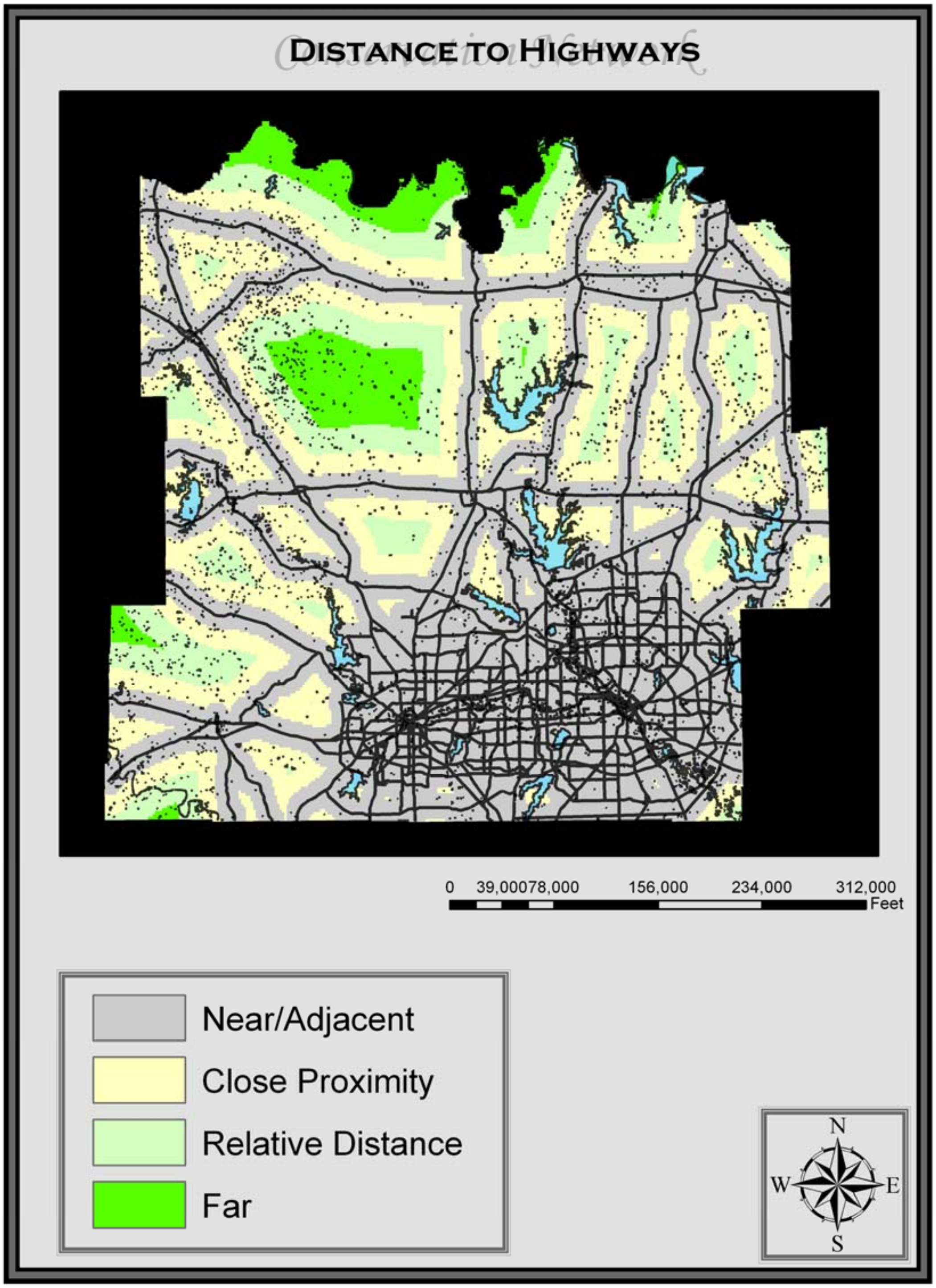


Figure 11: Distance to Major Highways.



Where the LSI values may fail to delineate wildlife corridors the processed riparian buffer shows potential to connect highly suitable areas, FCA's, and perhaps even corridors where land-based corridors are susceptible. The riparian buffers were processed through a multi-step analysis, beginning with the original stream segments layer, extracted to the rural landscape, then selected amongst LSI values over 70% to produce rural streams with high LSI values. These riparian corridors are most likely the most utilized wildlife corridors functioning both as transportation routes and offering most food, water, and shelter requirements. Although each stream was not analyzed in-depth as the landscape, ecoregions, and FCA's their contribution to the conservation network may be tremendous, and hopefully will be the backbone of future research on functional space and place.

Apart from the predominant emphasis placed upon the LSI model and spatial analysis habitat within the North Texas study area and each ecoregion was assessed using landscape metrics to determine the dominant cover types. Landscape metrics can be useful in determining several attributes of the environment and applicable to environmental quality assessments, habitat suitability, and impervious surface calculations (Wade et. al., 2003). In this paper the major features were assessed per Land Cover Proportions (LCP) in the study area, ecoregions, and FCA's while also utilized as a cross-reference for the proposed FCA's and wildlife corridors.

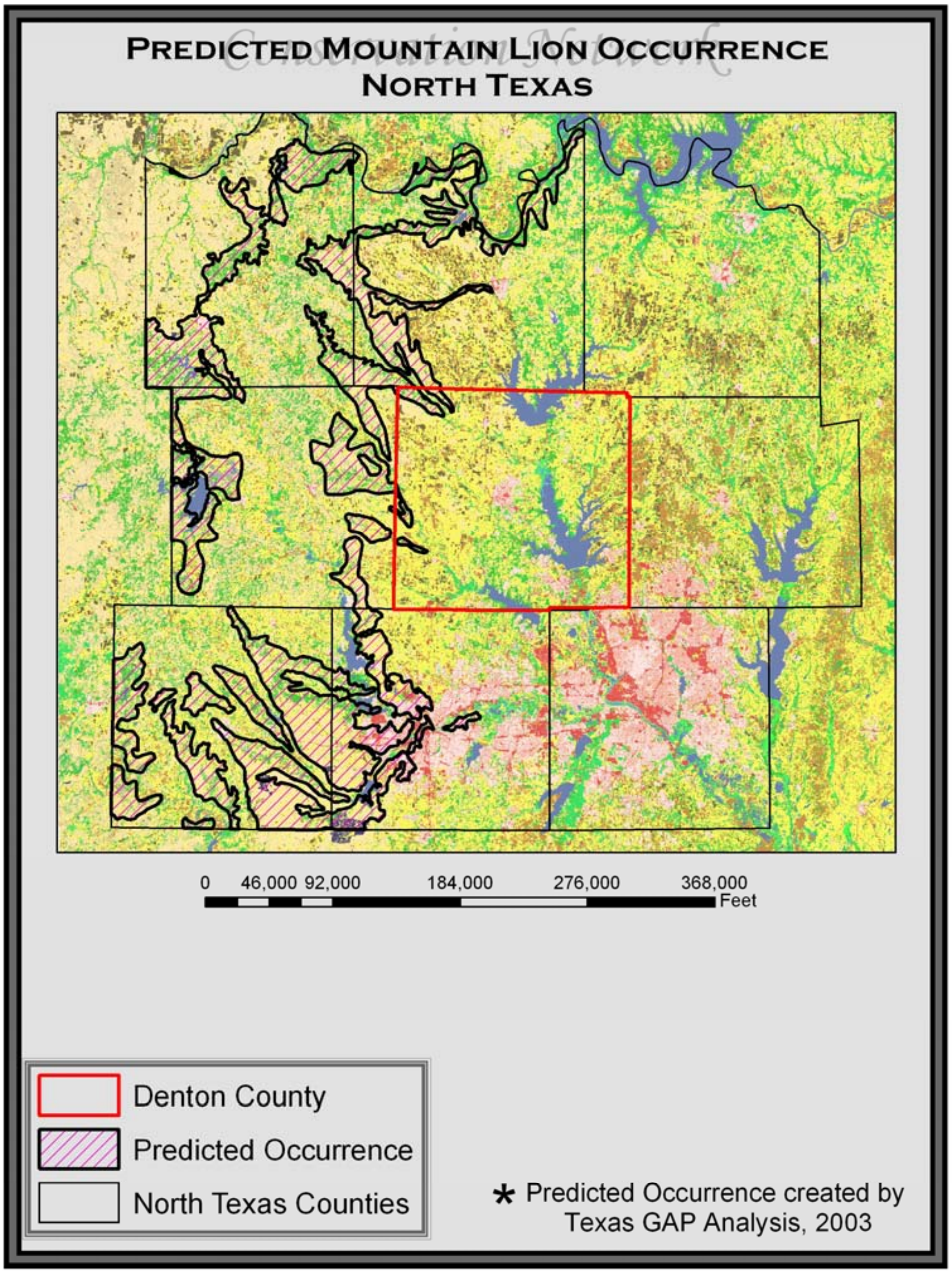
Table 4: Land Cover Proportions for Ecoregions in North Texas. Data based off of MRLC 2001 Land Cover.

Land Cover Type	Western Cross Timbers	Grand Prairie	Eastern Cross Timbers	Blackland Prairie
Water	15,218.93	25,798.81	77,425.45	60,153.87
Urban- Low	64,549.65	82,788.89	72,293.35	151,651.58
Urban-Moderate	20,084.27	90,940.50	76,113.83	193,731.71
Urban-Medium	3,943.32	36,011.32	40,796.90	136,365.79
Urban-High	1,029.55	20,986.46	17,865.02	72,670.45
Barren	4,451.75	1,349.57	1,617.32	1,486.48
Deciduous	246,232.90	88,733.91	159,080.78	165,509.27
Evergreen	15,325.54	3,285.67	14,784.05	19,183.03
Shrub	31,833.12	988.78	311.11	988.62
Grassland	757,426.61	589,672.46	245,446.52	428,296.14
Pasture	107,105.33	140,378.38	97,707.47	150,102.64
Crops	48,763.71	103,753.51	24,996.80	204,678.07
Riparian	6,149.41	2,305.92	4,893.94	18,063.62
Wetlands	80.79	768.76	3,191.93	7,866.52
Dominant Vegetation	Grassland, Deciduous Forest	Grassland, Pasture	Grassland, Deciduous Forest	Grassland, Crops

In the LCP table above it can be seen that the WCT may retain the most spatially integrated within the study area with the dominance of forest and grassland followed by crops and shrub. In stark contrast the Blackland Prairie retains a marginal proportion of natural habitat with crop and urban land cover types dominating the LCP's with grassland in-between them. However, most of the grassland is highly disturbed or heavily manicured and will require intensive restoration efforts to be resemblant of a prairie. The Grand Prairie and ECT ecoregions show a balance between forest and crop.

After all GIS layers were processed and converted to a standard projection, State Plane North Central Texas 4202, and 10-foot cell size it was possible to initiate spatial analysis using ArcGIS 9's advanced analytical tools. Separate masks were created for the total study area, rural landscape, each ecoregion, Denton County and the FCA network. The major roads layer was converted from vector to raster using both road density and distance to roads before choosing the latter due to its larger spatial extent of influence. A prey model was created for the two primary predators of this study, mountain lion and bobcat, with a weighted average of 50% given to white-tailed deer. Secondary species of the prey model included the eastern cottontail (10%), opossum (10%), skunk (10%), armadillo (10%), northern bobwhite (5%), and fox squirrel (5%). Considering that mountain lion distribution is still speculative the data provided by the Texas Gap report was supplemented with sightings by county from 1982-1997 by TPWD authorities, and general consensus among public sources that mountain lions are present in the area (TPWD, 1998).

Figure 12: Predicted Mountain Lion occurrence for North Texas devised by Texas GAP Project (Parker et. al., 2003)



From the distribution map above it can be seen that mountain lions are most heavily distributed along the western portions of the North Texas microregion which may be a source area for local populations. In addition, it could signify the necessity of strengthening current reserves and adding new ones within its range. Meanwhile, the mountain lion's political status still presents numerous problems and requires amendments, such as protection of the species from the current year-round hunting, and the prohibiting the aforementioned hunting of pregnant females and cubs currently allowed. Without political protection geographical integrity of the lion's range will only be slightly improved and possibly ineffective.

The North Texas regional assessment relied primarily upon a GIS model used for the early phase of this analysis to create a regional Landscape Suitability Index (LSI) covering the entire study area: 5,284,949 acres. Five principal, reclassified layers were used with an equal weight: distance to cities, proximity to parks, species richness per distribution, distance from major roads, and land cover divided into graduated color classes to distinguish inhospitable, medium, and suitable areas.

LSI results were applied to each distinctive mask either through extraction or a separate LSI model tailored for the unit of analysis. Considering that the primary goal of this paper was to assess the landscape for potential corridors and unprotected ecological areas the classification used was fairly strict, giving high values to the most optimal attributes of each layer, and eventually focused primarily on ratings above 70%. The top 30% of land area depicted by the LSI should be employed to identify priority regions where expanding a current FCA, conserving corridors, or locating a new FCA. It will be absolutely necessary, however, to strengthen each raster layer used in the model and to acquire smaller-scale data from local sources. One of the greatest difficulties in the data acquisition was the incongruency between data sources. For example, the northern three counties of the study area are excluded from the principal data source of this region: North Central Texas Council of Governments (NCTCOG).

In addition to the GIS and spatial analysis methodology each FCA, ecoregion, and species was assessed from an ecological viewpoint to complement the geographical emphasis of this paper although embedded into the analysis rather than treated separately. Given that some data layers are inaccurate, incomplete, or outdated it was necessary to consult wildlife literature and expert opinions to verify the extent of ecosystems, habitats, and species, and their respective characteristics and functions in order to grasp the essence of each subject. The FCA's are rightfully considered geographical places, and each area should be analyzed individually for their subjective strengths and weaknesses, and for their dominant features not included in the geographical assessments, e.g. major birding centers, mammal dispersal routes, grassland management, recreation, hunting, etc. Nevertheless, ecological assessments and analysis were not separate but adjoined to each step of the research methodology as a cross-reference or source of critical debate.

The local conservation models employed for Denton County followed a methodology different from the regional model in reducing the cell size to 10 feet, inclusion of local factors, more in-depth analysis of habitat and open space. A union of both FCA's were used as the major mask for analysis: the Ray Roberts State Park and Greenbelt Area, and the Lake Lewisville Environmental Learning Area. Due to the lack of data cohesion and integration model parameters utilized a separate land cover layer from the regional model, provided by the Center for Spatial Analysis and Mapping

(CSAM) spearhead by the University of North Texas. Furthermore, unlike the land cover classification adapted from the Texas GAP Analysis local data was overlaid upon a 2005 Aerial Photo provided by the Denton County Planning and GIS department to verify the accuracy of habitat delineation and types. In addition, the regional model's reliance upon major roads and highways was substituted for by a local roads layer which included minor and county-maintained roads lacking in the regional database. Also, the availability of planning layers, such as parcels, subdivisions, development permits, and gas wells allowed for the creation of a separate development index to be incorporated into local analysis- all of which were lacking for the regional model. A major tenet for the local model relied upon the verification of forest, shrub, grassland, and wetland habitat using the 2005 Aerial Photo, which would become the basis for mapping contiguous habitat as the basis for both proposed FCA's and habitat corridors. Unlike the regional model where corridors were created from the LSI index local habitat corridors were drawn from the land cover overlaying the aerial photo to ensure that FCA's and corridors fell within the true habitat boundaries. Unfortunately, this process was not available for the regional model which results in some incongruency between the two models. Nevertheless, the coarse-filter regional model provided preliminary results which were useful in establishing the fine-filter local model given the discrepancy in data availability. The local model ultimately functions as a more accurate and detailed analysis at a much finer scale required for local planning. In effect, local land use, development, and ownership were incorporated into the analysis of conservation areas and corridors. Furthermore, it provided the opportunity to assess habitat qualitatively, such as highly developed forest versus undeveloped forest.

Figure 13: CSAM Land Cover created by UNT faculty and Staff.

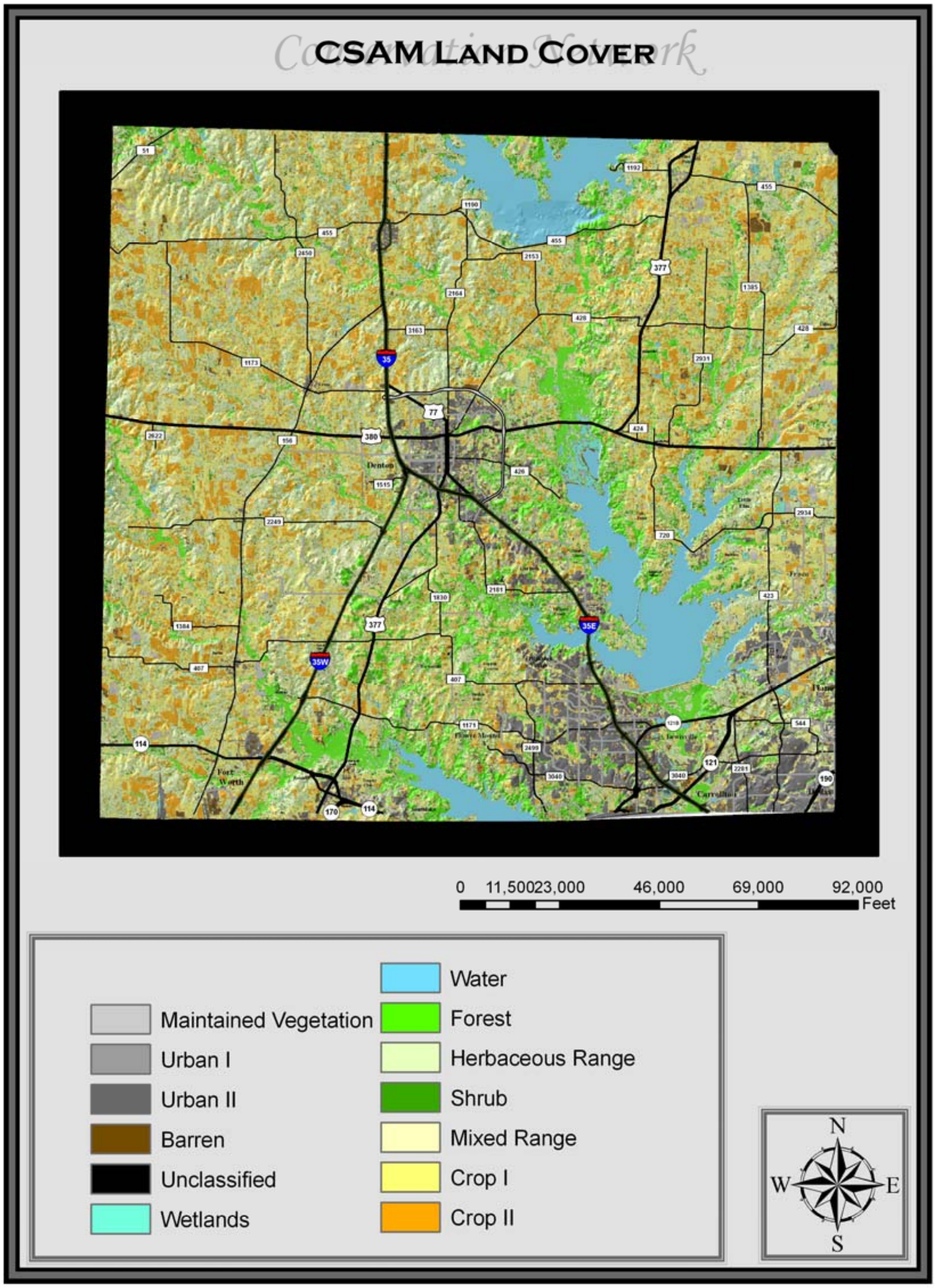


Table 5: Land Cover Proportions (LCP) for Denton County, FCA 1 & FCA 2 created from land cover classification by Center for Spatial Analysis and Mapping (CSAM) at UNT.

Land Cover	Acres	LCP %	FCA 1 Acres	FCA 2 Acres
Wetlands	4,437.89	0.07	32.41	254.15
Water	43,407	7.1	184.84	396.89
Forest	57,015.85	9.3	2,171.04	4,561.06
Range/Pasture	174,754.91	28.51	6,886.08	2,425.20
Shrub	20,488.64	3.34	646.74	10.94
Crop	244,623.55	27.42	4,109.86	1,818.84
Urban	45,337	7.56	4.81	130.49
Maintained Vegetation	11,086.47	1.8	26.57	341.76
Barren Ground	11,697.71	1.9	48.35	90.55
Unclassified	38.76	<1	0	0
Dominant	Crop, Range, Forest		Range, Crop, Forest	Forest, Range, Crop
Total			**14,110**	**10,030**

Various development factors or coefficients were created from a composite calculation of four reclassified factors and used to assess open space and habitat as part of and separate from the local LSI: road density, development permit density, subdivision density, and gas well density. All four layers were the most current data available from

Denton County and included new features that were updated at the time of this research and writing. The composite index was then applied to the analytical masks: the FCA's, habitat corridors, regional corridors, and ecoregions. Following this application the development index was reclassified and incorporated into the local landscape suitability index combining land cover, parcel analysis, and species' distributions for a finer-scale assessment. The parcel layer was reclassified by land type, with the highest values ascribed to woodland, unimproved pasture, native prairie, and undeveloped while lower values ascribed to a range of developed land types: commercial, crop II and III, improved pasture, wasteland, improved lot, common area, residential and homesites. Meanwhile the species distribution assessments were adapted from the Texas GAP Analysis to test the ranges of general and indicator species with the emerging conservation network. Such a process clearly emphasized an iterative process outlined in other research applications noted previously. Furthermore. Both the FCA's and corridors would exhibit a range of values reflecting their degrees of development or naturalness, in addition to containing a range of values for suitability as functional areas.

The final local LSI incorporated six biogeographical and cultural factors in a weighted calculation: land cover (30%), road density (20%), urban-rural interface (20%), mammalian, avian, and reptilian species distributions (10%), gas well density (10%), and subdivision density (10%). All factors were reclassified on a scale from 0 to 3, with a value of 3 representing the highest level of geospatial suitability. The final calculation was standardized to a percentage scale from 0 to 1 with 1 representing 100% suitability. Results for the model allowed a fine-coarse assessment of the county landscape, primary ecoregions, FCA's, conservation areas, habitat corridors, and a means to identify and assess unique geographical places which were not addressed in the conservation network in entirety. The inclusion of geographical places helped clarify the pursuit of functional place as much as functional space defining this research. Functional places included ecologically significant microhabitats and historical viewsheds used by both indigenous tribes and early north texas settlers- Pilot Knob, Bald Knob, Long Point and Crawford Hill. Both the anthropogenic hill located near the present-day Radisson Inn Hotel and Pilot Point were excluded from analysis. In addition, unique functional places throughout the landscape were included which represented natural habitat or scenic views. Two of the primary areas included a wetland-forest habitat along highway 380 eastward of Cross Roads and near the emergent Paloma Creek subdivisions, Pilot Knoll Park near the Lantana Subdivision, and the Rainbow Valley Cooperative sponsored by the Natural Areas Preservation Association (NAPA).

An additional analysis of natural habitat and open space was created exclusively to address the needs of mountain lions. This Mountain Lion Habitat Suitability Index (HSI) followed the same technical principles established in the local LSI model but derived its parameters from the most recent research on mountain lions preferred habitat, prey selection, distribution, life needs, dispersal patterns, and migration through corridors. In addition, it followed the Habitat Evaluation Procedures (HEP) implemented by the U.S. Fish and Wildlife Service, which includes the creation of a HSI and delineation of Habitat Units (US FWS, 1980; US FWS, 1981; Canter, 1996). Since this is a geographical research anomaly and application the HEP, HSI, and HU's were tailored for a geographical assessment. For example, the LSI values were converted to

Landscape Units (LU's) for the general geographic assessment while the Mountain Lion HSI includes actual HU's for each land cover type similar to the US FWS procedures.

Factors used for the Mountain Lion HSI were in part derived from the local LSI model but added new coefficients which address specific needs of America's most widespread carnivore. The primary additions were the predicted distribution of its preferred prey: white-tailed deer, opossum, fox squirrel, skunk, bobwhite quail, eastern cottontail, and armadillo. Although the mountain lion is widely held to be a generalist predator most of the literature suggests its preference for white-tailed deer and other members of the deer family. The composite prey index attributed rank values per species before the final input layer was created and implemented in the HSI: white-tailed deer (50%), opossum (10%), skunk (10%), eastern cottontail (10%), armadillo(10%), squirrel (5%), bobwhite quail (5%). It is worth mentioning that mountain lions will pursue other prey species, including coyotes, bobcats, domestic livestock, domestic pets, and numerous other species which occupy its range. However, the domestic species which have found their way into the diets of many western cats is not included here simply because conservation of mountain lions depends heavily upon maintaining an adequate buffer between them and humans, moreover between them and domestic animals. In this case specifically it implies large geographical space away from primary human activity and where its natural prey is abundant.

In addition, the Mountain Lion HSI includes added geographical coefficients not included in the local LSI to address movement patterns: distance to highways, and slopes. These coefficients were included to address the mountain lion's tendency to avoid major highways unless sufficient underpasses are present, and the tendency to move through habitat on gentle or flat slopes rather than the rugged, steep slopes normally attributed to them. Afterall, their historical range encompassed virtually every major ecosystem and geographical area of the United States, most of which has been converted into urban, suburban, agricultural, commercial, and industrial land types. Research on their preference for the same ideal environmental conditions humans prefer was largely lacking and instead limited to marginal habitats in the west and near mountainous areas. For an effective conservation plan meeting their needs, however, some of the land we consider ideal is also their preferred habitats and for fairly similar reasons. The literature suggests that mountain lions prefer to follow gently sloping riparian land cover for movement, and that cover and prey distribution may be the single most important factors (Beier, 1995). The reclassified land cover and road density layers were the only coefficients retained from the local LSI model.

Figure 14: LSI Model Coefficients and Flow Chart showing all processes involved in LSI model.

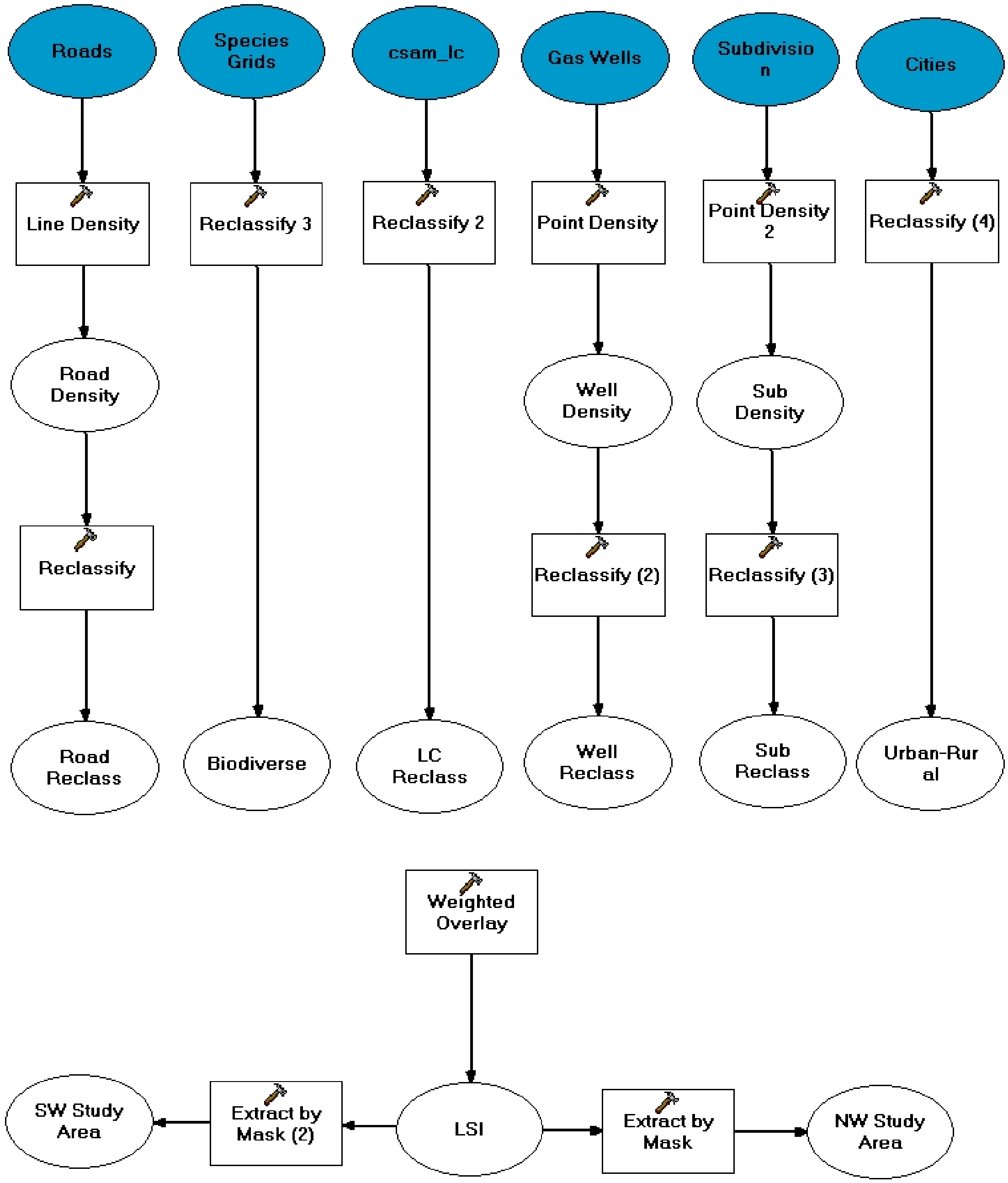


Figure 15: Mountain Lion corridor movement HSI coefficients and flow chart for model creation.

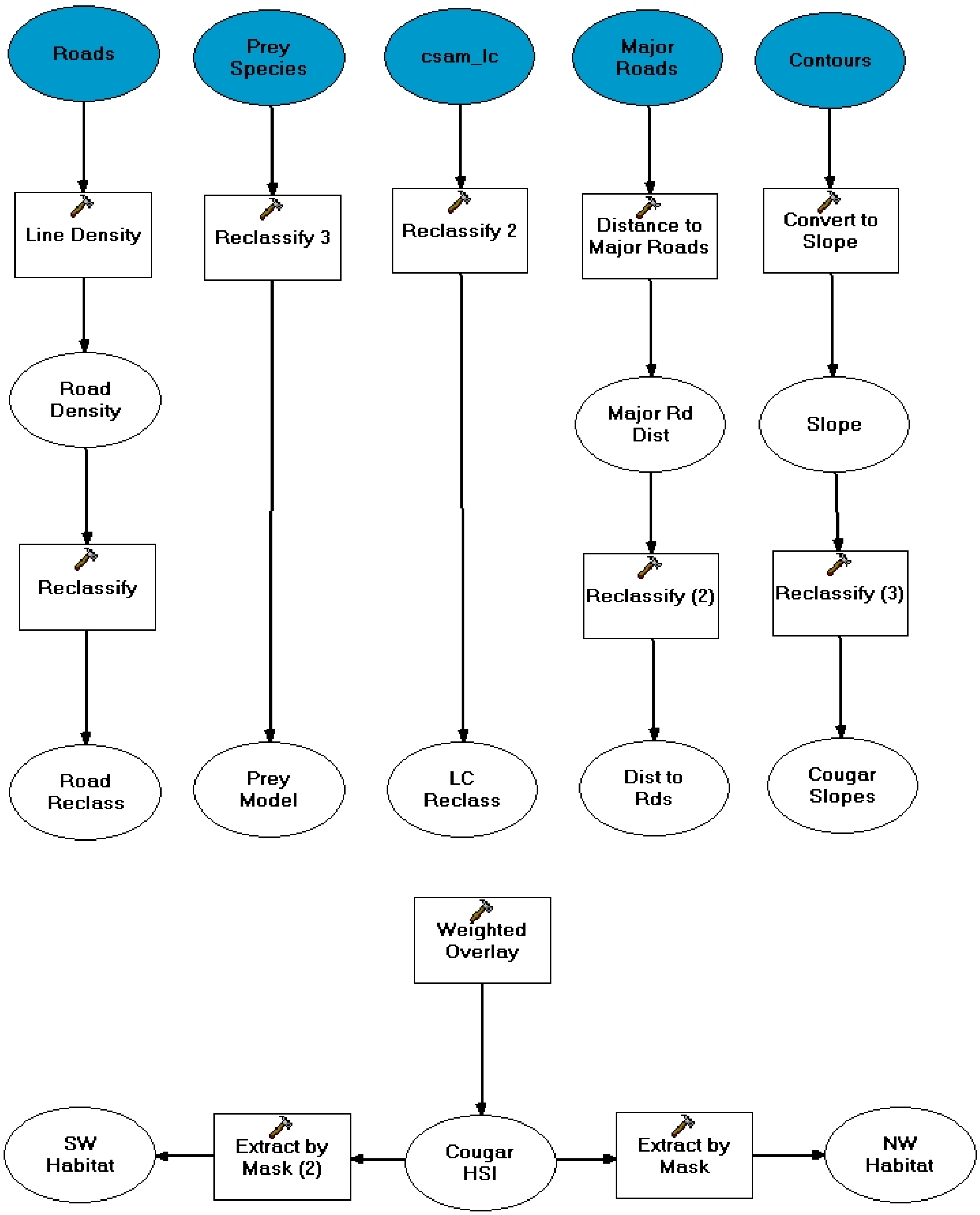


Figure 16: Reclassified Habitat layer emphasizing natural forests, shrub, wetlands, and grasslands.

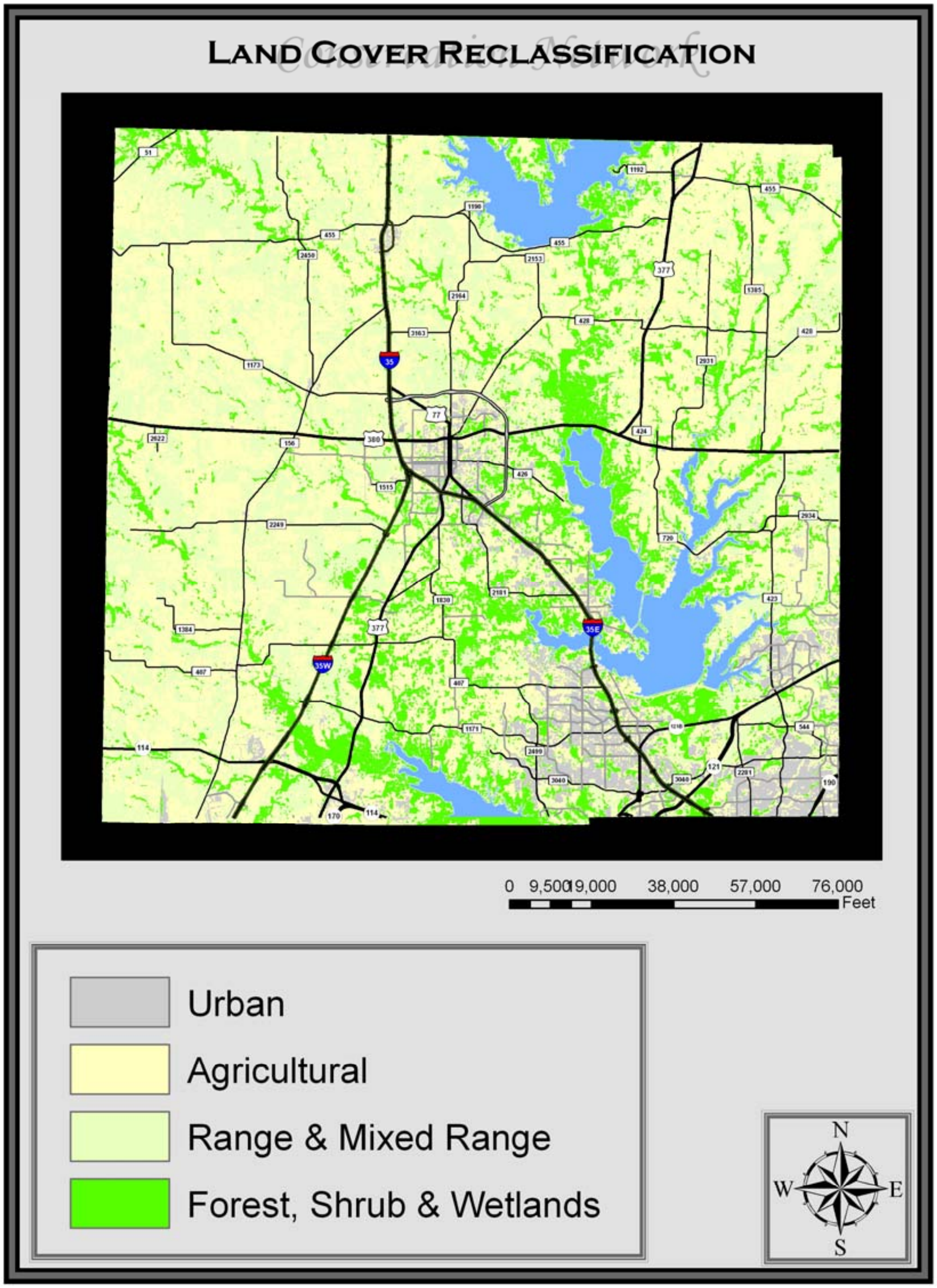


Figure 17: Reclassification of Road Density for Denton County. Green areas represent low density or the few remaining pockets of roadless areas in the county.

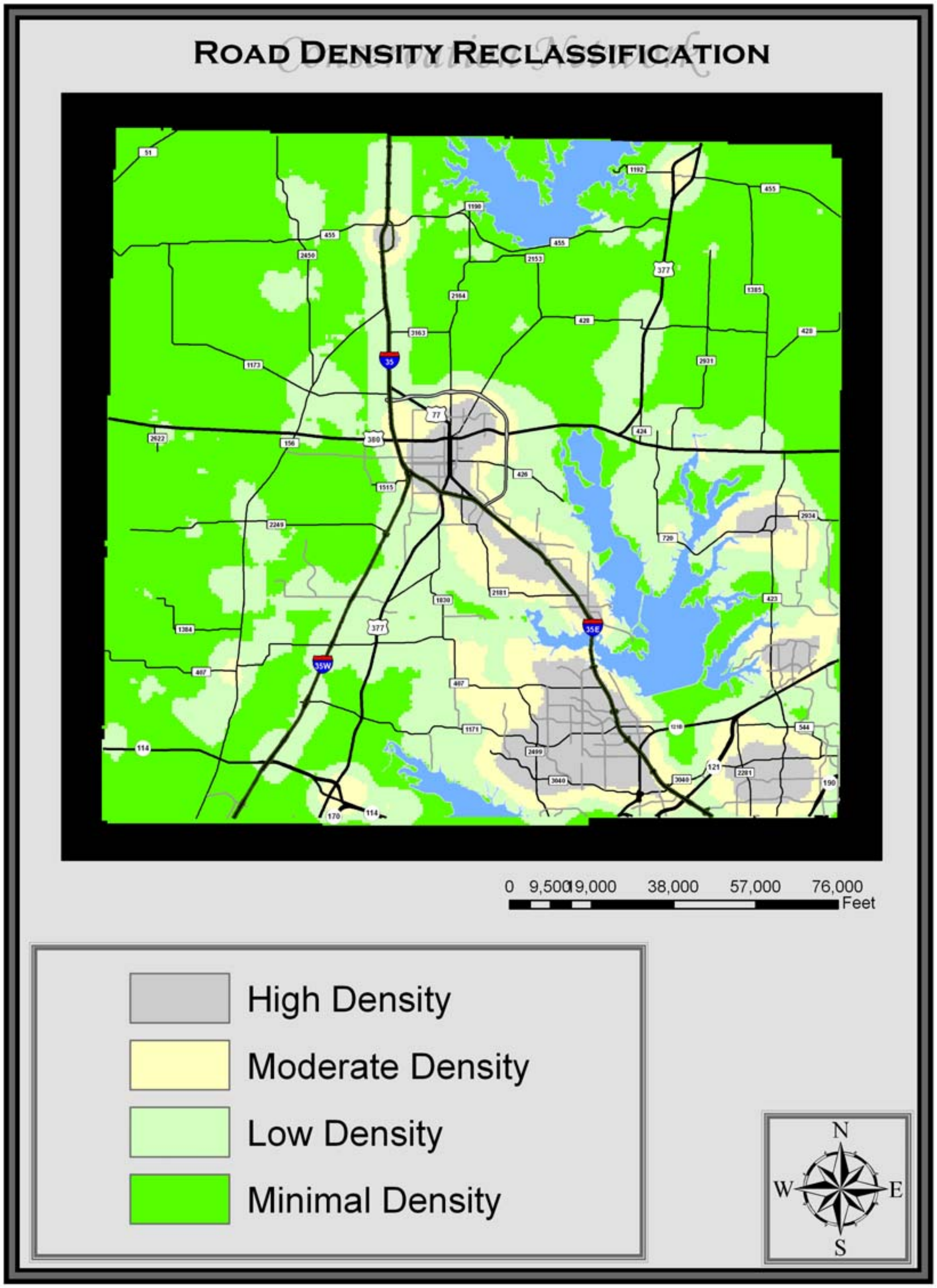


Figure 18: Reclassification of Landscape into rural unincorporated, Extraterritorial Jurisdiction (ETJ), and Municpal boundaries. Only rural unincorporated and ETJ were included in primary habitat and landscape models.

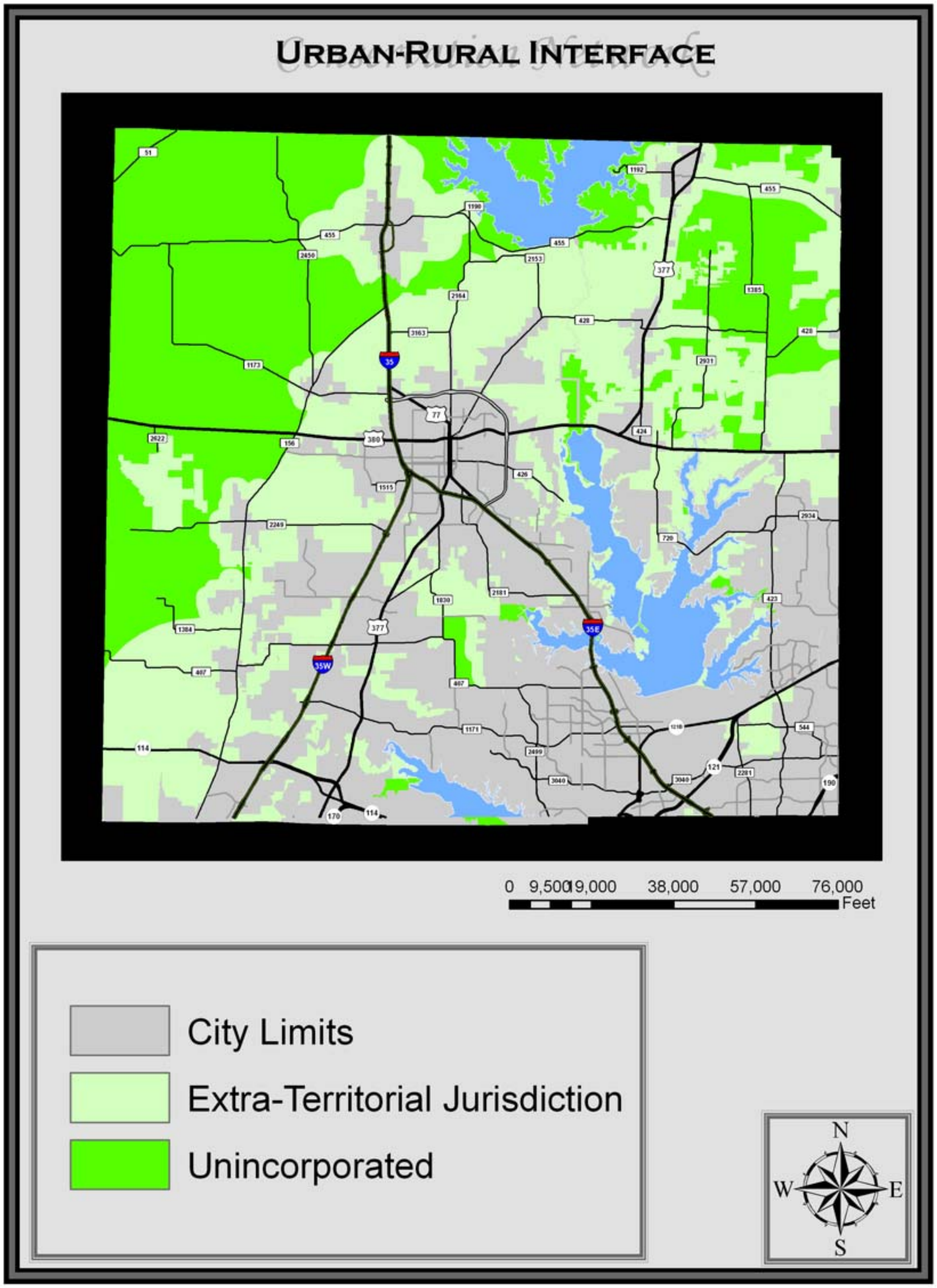


Figure 19: Reclassification of Gas Well density to illustrate concentrated areas of resource exploitation.

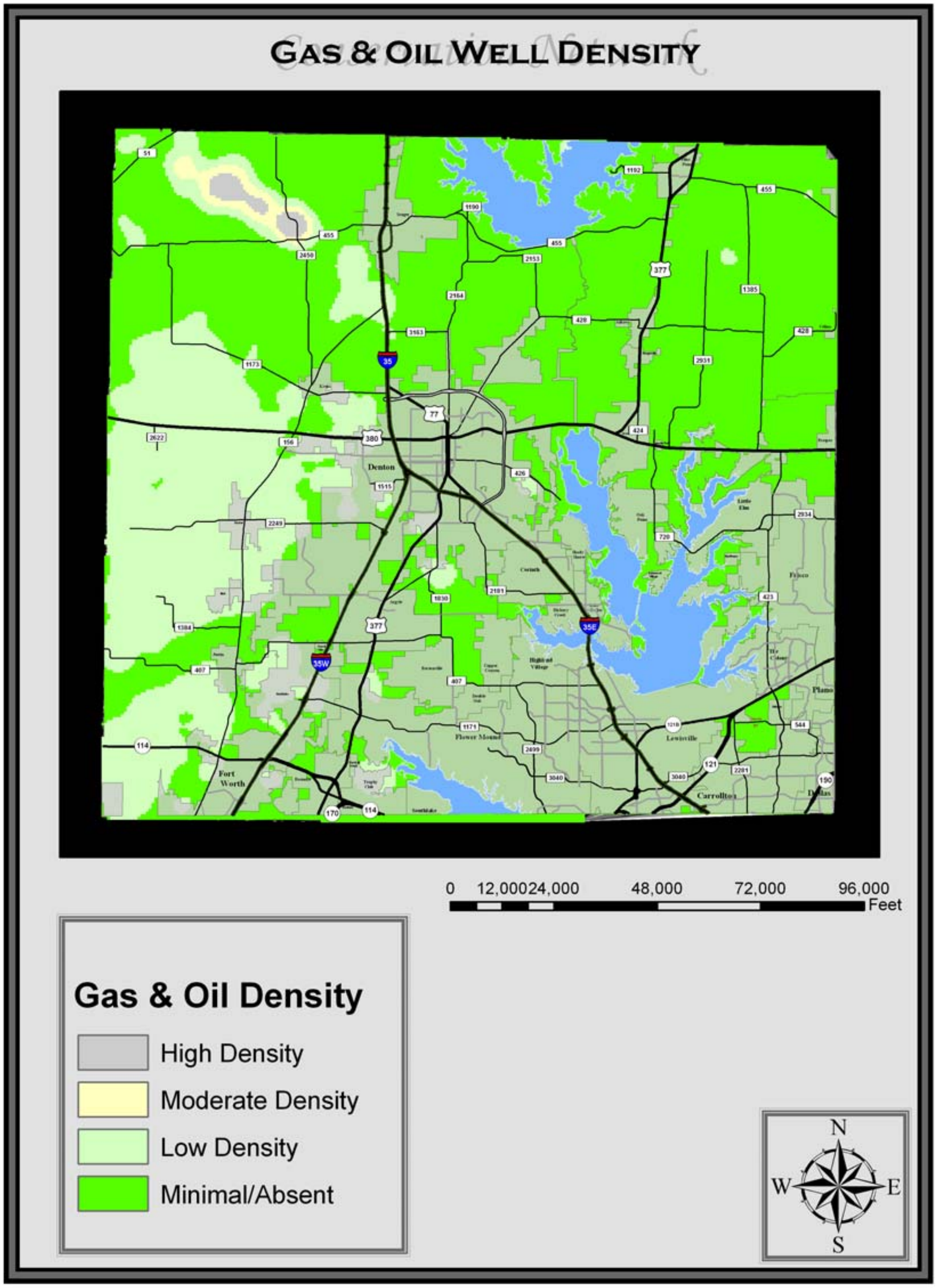


Figure 20: Reclassification of Subdivision Density to illustrate the primary areas of the county under development pressure.

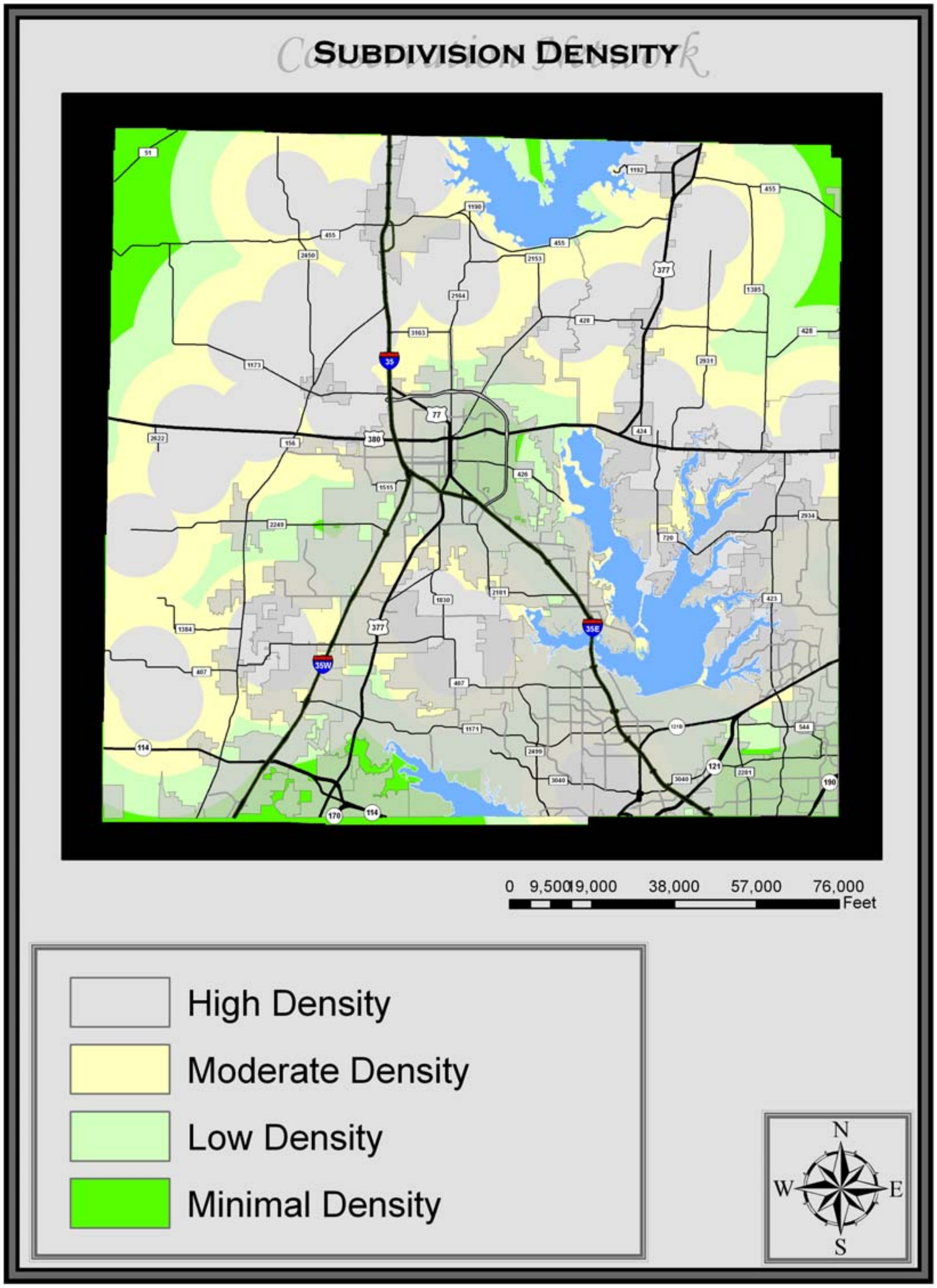


Figure 21: Composite distribution hypergrid of mammalian, avian and reptilian species processed from Texas GAP Analysis (Parker et. al., 2003).

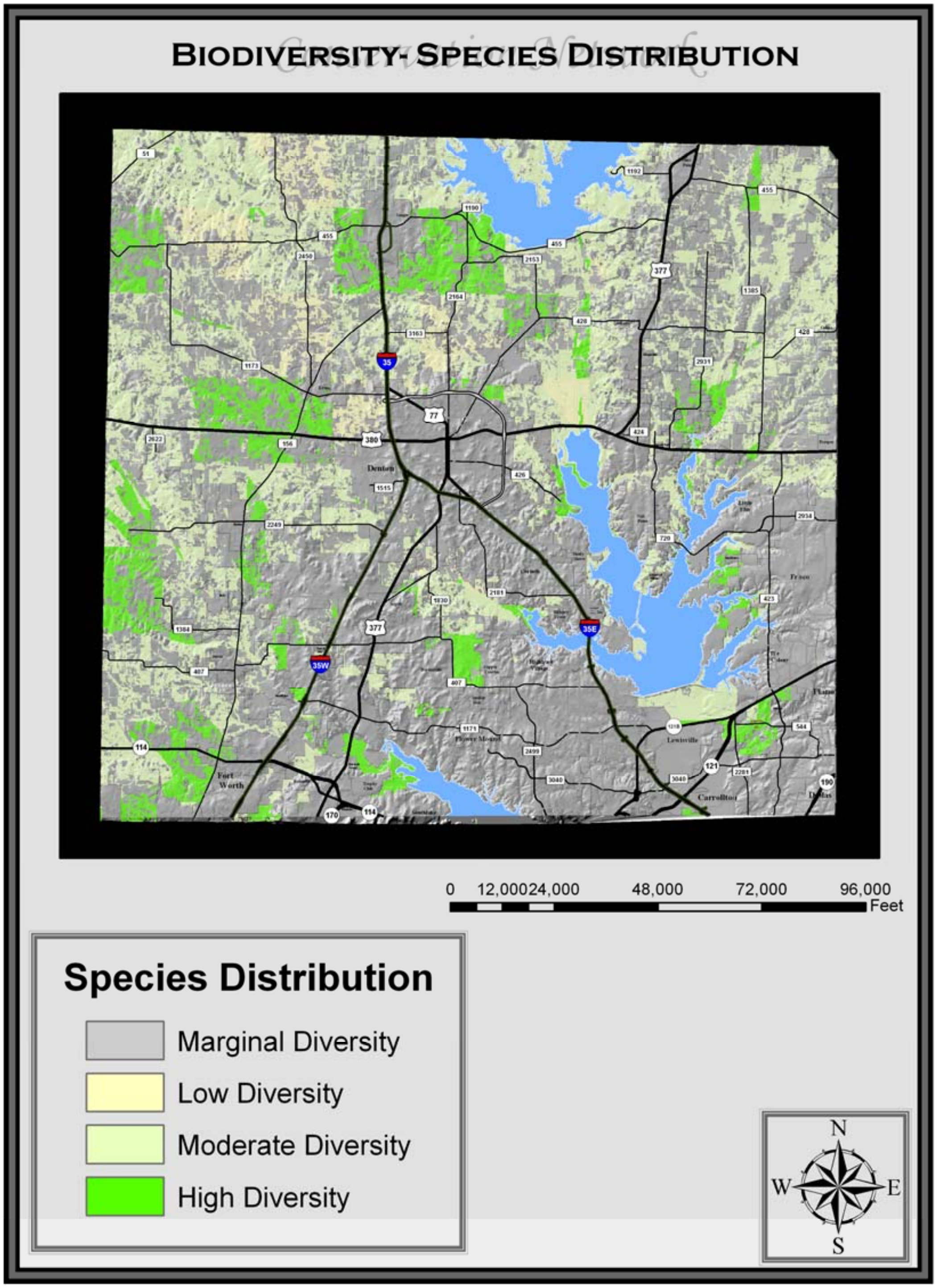


Figure 22: Denton County Slopes created from 2-foot contours.

CHAPTER V

RESULTS

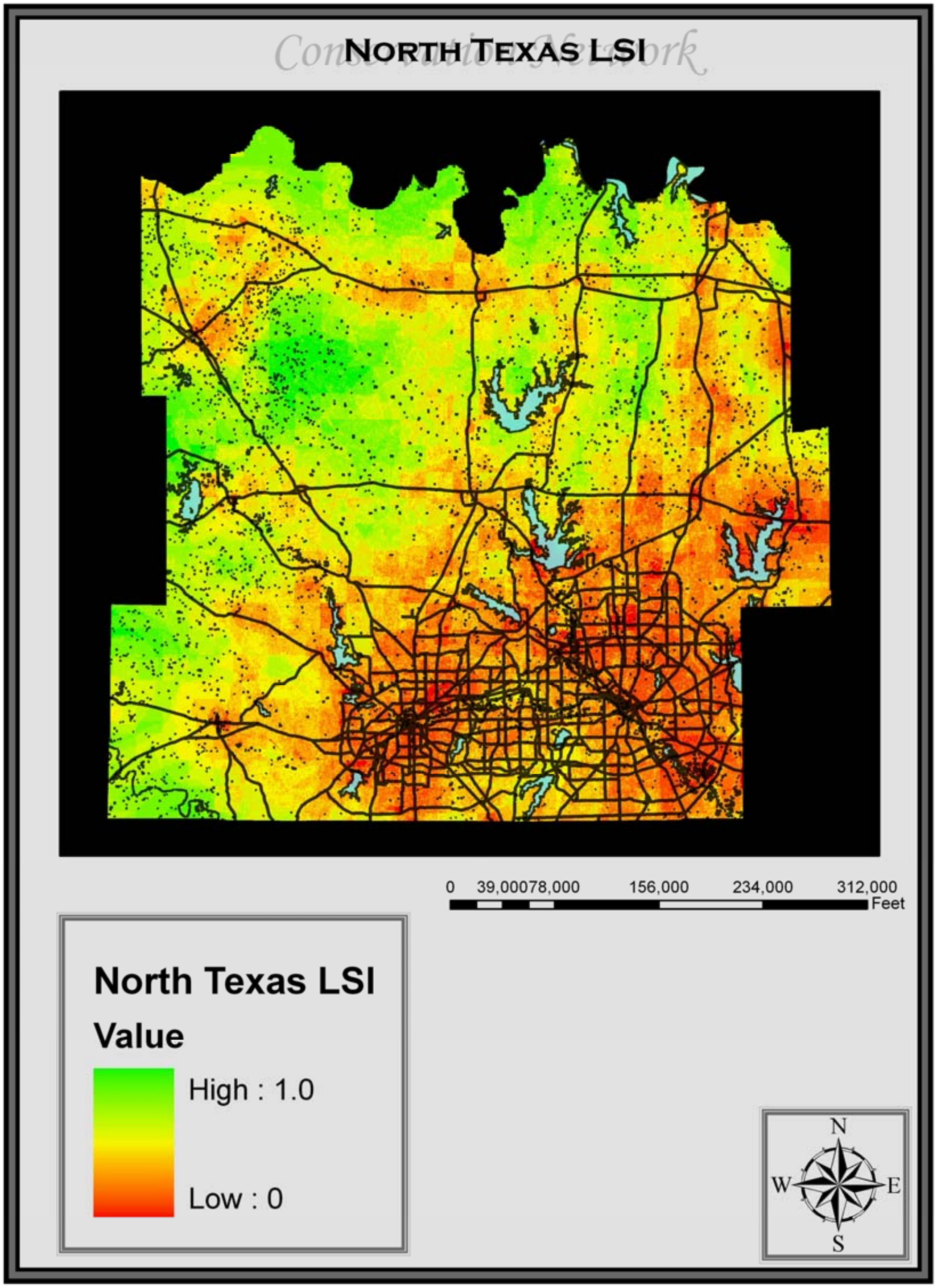
Regional LSI

LSI values for the North Texas study area and rural landscape appear to be most promising with 15.25% and 20.54% of each respective area over 70% suitable. The study area in particular has potential ecological areas in the northern, western, and northwestern sections exceeding optimal values. Both the central and southeastern sections are embedded in areas of low LSI ratings and amidst the metropolitan areas. The majority of the land falls between 0.20 and 0.80 in the LSI. Meanwhile, the rural mask at the center of locating new FCA areas and wildlife corridors possesses sections of high LSI values in the northern, western, and northwestern areas while the southern exterior and southeast portions show high levels of human impact. The dominant land LSI values for the rural landscape fell between 0.33-0.80 which suggests a high potential for low to mid value land areas to be future links or hubs in a larger conservation network. With over 20% of the rural area surpassing 0.70 LSI approximately 800,000 acres of land are potentially suitable for wildlife inhabitation and new FCA locations. An optimal location for reserve selection can follow areas of contiguous high-rating areas as suggested in the distribution of LSI values.

The major ecoregions of this study showed marked differences, particularly between the two extremes of the Western Cross Timbers and Blackland Prairies. While the former appears to have the greatest potential for conservation efforts with over 30% suitability the latter is the most impacted and fragmented landscape with only 4.1% deemed suitable. The highest concentration of suitable land within the Western Cross

Timbers occurs in the north-central and southwestern sections of the WCT mask. The majority of the region lies between 0.46 and 0.80 suitability. Meanwhile, a small pocket in the northwestern Blackland Prairie ecoregion has potential conservation value. The vast majority of the Blackland Prairie falls between 0.20 and 0.53 suitability, far below the 70% standard considered necessary for landscape functionality. The Eastern Cross Timbers has similar LSI values to the WCT at 18.31% suitability except only the northern section of the region appears to be truly suitable or ideal. The vast majority of the ECT landscape lies between 0.46 and 0.59. The Grand Prairie ecoregion may have greater potential for a grassland ecosystem than the Blackland Prairie although its overall distribution within the north-central section totals only 9.97% of the total area, while the majority falls between 0.33 and 0.66 LSI. Although much smaller in area and secondary to the major ecoregions of this study the Oak and Mesquite regions contain areas of potential habitat and could function as buffers for neighboring ecoregions. The Oak region has the highest ratings in the western and eastern sections while the Mesquite was predominantly suitable or within an acceptable range. From the results it is clear that Western and Eastern Cross Timbers hold the greatest potential for conservation efforts and retain some degree of functional space and places.

Figure 23: Regional LSI results for North Texas study area. Areas in shades of green highlight upper range of suitability values for landscape units. Red areas depict highly urban and/or fragmented areas.



In the LCP table it can be seen that the WCT may retain the most spatially integrated land cover within the study area with the dominance of forest and grassland followed by crops and shrub. In stark contrast the Blackland Prairie retains a marginal proportion of natural habitat with crop and urban land cover types dominating the LCP's with grassland inbetween them. However, most of the grassland is highly disturbed or heavily manicured and will require intensive restoration efforts to be resemblant of a prairie. The Grand Prairie and ECT ecoregions show a balance between forest and crop.

Table 6: Landscape Suitability Index (LSI) Per Study Area and Rural Landscape.

LSI	Study Area	Rural Landscape
0-0.10	9,914	1,573
0.135	48,801	11,808
0.2	330,259	63,484
0.26	383,869	133,591
0.33	462,036	242,600
0.40	610,077	353,978
0.46	708,510	514,377
0.53	750,846	649,344
0.60	588,702	563,886
0.66	585,751	580,898
0.73	345,391	345,107
0.80	275,220	274,792
0.86	128,997	128,742
0.93	35,190	35,124
1.0	21,382	21,382
Upper Tier >0.70	**15.25%**	**20.54%**

In the LSI table it can be seen that the dominant high value land LSI values are concentrated in the western and northern regions of the rural landscape. The rural LSI values were the primary basis for creating wildlife corridors and proposing new FCA's based upon the principle of maximum geospatial coverage. For instance, corridors were drawn using ArcGIS 9.1 advanced editing tools to create polylines following the high LSI areas as much as possible while several links fall within medium to low range values. Furthermore, the new FCA's were created by first establishing a point feature in homogenous land areas above 70% suitable and creating a 10,000 foot buffer to produce four windows with each containing approximately 7,212 acres of suitable land.

Table 7: LSI Per Ecoregion

LSI	West Cross Timbers	Grand Prairie	Eastern Cross Timbers	Blackland Prairie
0-.10	0	1,166	652	8,133
0.135	87	11,777	5,120	31,725
0.20	2,338	78,974	26,849	220,462
0.26	11,522	81,347	56,509	229,940
0.33	33,199	114,193	71,900	235,217
0.40	72,379	174,267	83,452	265,611
0.46	133,261	212,867	109,107	223,689
0.53	222,750	180,158	134,040	170,448
0.59	215,945	113,682	103,136	96,026
0.66	228,268	100,722	90,167	61,041
0.73	147,392	59,127	65,123	43,173
0.80	135,773	37,888	53,381	18,272
0.86	68,301	17,414	33,571	3,497
0.93	28,284	3,275	501	190
1	20,694	687	0	0
Total Acres	**1,320,224**	**1,187,546**	**833,509**	**1,607,546**
Top 30%	**30.33%**	**9.97%**	**18.31%**	**4.1%**

Results for the mountain lion LSI revealed significant promise in areas along the western and northern borders of the study area. Overall, 25% of the mountain lions predicted range was considered suitable with LSI values over 70%. However, the bulk of these acres were between 70-86% with only 2.1% of the suitable land base falling into the 93 and 100 percentile range at approximately 17,500 total acres. The lion's total range was 806,985 acres out of the total 5,284,949 acres of the study area. In other words, the lion’s presence in North Texas is limited to pockets or geographical streams limited to the western half of the study area.

Local LSI

The final stage of the iterative process was applying a quantitative measure of environmental quality for functional places and space which could be used to support the development of a conservation network. A local Landscape Suitability Index (LSI) was created for Denton County with a similar methodology to the regional LSI but with fine-coarse factors incorporated into the analysis. All factors were resampled to a 10 foot cell (100 square feet per raster cell) and reclassified into a scale from 0-3, with 3 being the most suitable for conservation design. The Texas GAP land cover layer was replaced with a locally derived land cover layer created by the Center for Spatial Analysis and Mapping (CSAM) at the University of North Texas. The Denton County land cover could ultimately be verified and corrected with the 2005 Aerial photo which proved more reliable and accurate than the regional model. Additional factors included parcel land types to reflect land use patterns, gas and oil well density, road density, subdivision density and growth, and the predicted occurrence for avian, reptilian and mammalian species. All factors were resampled and reclassified to a common scale in order to implement the raster calculator tool to create the fine-coarse LSI. Land cover types were ascribed values according to their degree of naturalness with a value of 3 given only to forest, shrub, wetlands and water while cropland, pasture and highly maintained vegetation were given either values of 1 or 2 depending upon the intensity of use, and all urban classes ascribed the lowest value of 0. Parcel land types were reclassified into categories which prove favorable for conservation purposes with highest values attributed to undetermined, undeveloped, native pasture, woodland, timber and waterfront lots exclusively. Agricultural land types were given a value of 1 to depict their semi-functionality as space to migrate through but ultimately insufficient to support and protect wildlife let alone natural vegetation. Meanwhile, urban and development land types were ascribed values of 0.

Results for the local LSI were similar to the regional model but ultimately more detailed with the increased spatial resolution and inclusion of local factors as the basis for analysis. The final range included values as low as 3 for the major urban areas of the county, primarily the cities of Denton, Lewisville, Flower Mound, Carrolton and the ETJ's of several cities in the southern region of the county. Values between 9 and 15 were abundant for most of the western and northern regions with parallel abundance in the eastern region. The highest value range between 12 and 15, which is 80-100% suitability on the LSI, were concentrated in the northwestern and northeastern sections of the county. Approximately 20.17% of the Denton County landscape fell within the upper tier of the index at 12-15, equivalent to greater than 80% suitability for location of an FCA. However, 11.29% and 5% of this upper tier was either 12 or 13 on the index, implying some degree of spatial or functional vulnerability. 23,125 acres received scores of 14 or 15, totaling 3.1% of the landscape and limited to already protected areas in the Greenbelt area. Nevertheless, the upper tier of the LSI totals 120,845 acres of land that is potentially suitable for an FCA, conservation area, or habitat corridor provided that land ownership and land use are conducive in these areas. The final selection of functional places and space would ultimately proceed from land areas falling within this range when applicable.

Conservation area 1 fell within the former range in spite of the highest area of gas well density. LSI values fell exclusively within the intermediate to high range, from 8-15. 7,638 acres of the total 14,010 acres, comprising 54.52% of the area were 12 or greater and helped narrow down the selection of an intact area of the initial spatial delineation to be conserved and for further analysis. The only identifiable threat to conservation area 1 is gas well development which seems largely unregulated and unsystematic in this portion of unincorporated Denton County. Otherwise, all other LSI factors were minimal or non-existent in the area, thus influencing the total values and high suitability. Meanwhile, Lake Ray Roberts State Park and the Greenbelt was the only geographical area in the county containing values of 14 and 15 for most of the area with the highest concentration of 100% suitability falling within the state park boundaries and comparable values for the bottom section of the greenbelt. As might be expected the northern section of the greenbelt received only moderate or mid-range values due to land use patterns surrounding the thinning corridor, or what might be called the interior of the state park and greenbelt union. Furthermore, conservation area 2 received a range of values with the most suitable land area extending from the central interior to the eastern boundary or western shore of Lake Grapevine. Over 2,407 acres of the total 11,113 acres were within the upper tier suitability range, a total of 21.66% that would be considered for the final delineation of an FCA. However, large portions of the area which fall into municipal or ETJ boundaries were in the intermediate range from 8 to 11. LLELA received mostly mid-range values with the highest range near its southern boundary and near the Trinity River floodplain while areas directly west and east of LLELA fell into the lowest ranges on the index, suggesting the spatial vulnerability of the area.

Meanwhile, corridor LSI values seem to suggest high suitability for both the Northwest and Southwest Corridors as they offer an opportunity to connect conservation areas 1 and 2 to Denton County's western border while also opening up the potential for a connection to the county's interior and to the Ray Roberts Greenbelt provided that adequate highway underpasses allow wildlife to migrate beneath them. The Northwest Corridor received relatively high suitability values for 34.38% of the total 15,984 acres, roughly 5500 acres of land area over 80% suitable. While most of the corridor crosses through major highways, most notably Interstate 35, large sections of the habitat corridor could support wildlife migration along the major waterways, such as Clear Creek, running through most of the area. The Southwestern Corridor received comparable LSI scores with 2,969 acres at over 80% suitable, approximately 24.27% of the total corridor's 12,233 acres. The primary functional places received the lowest LSI values of the subjects addressed, a point illustrating how fragmented the surrounding geographical space and landscape can affect the spatial and functional integrity of a place. Nevertheless, a certain level of connectivity can be delineated from the land cover and LSI values which may allow for the incorporation into the larger conservation network.

The final phase of Conservation Design would incorporate LSI values per conservation area and corridor to identify the most probable and suitable areas to be delineated as bona fide reserves, research areas, or for private conservation practices. Qualification for the final analysis required a mean score per parcel of greater than 80% suitability. Subsequent analysis reflects land use, economic values, and other associated factors to test the feasibility of acquiring the land, conservation easements, or the applications of other conservation measures when necessary. It is beyond the scope of this paper to discuss current management strategies by landowners within the study area, their future intentions to manage their land, and other planning issues which should be addressed in future research. Nevertheless, this research culminates with a sound basis and framework to contact affected landowners with concrete geographical delineations of conservation areas and the landowners involved in such areas. Moreover, several options have previously been outlined in the literature review, specifically from the NRCS Manual.

Figure 24: Localized LSI created from finer scale biophysical and cultural factors. Weighting system embedded in figure.

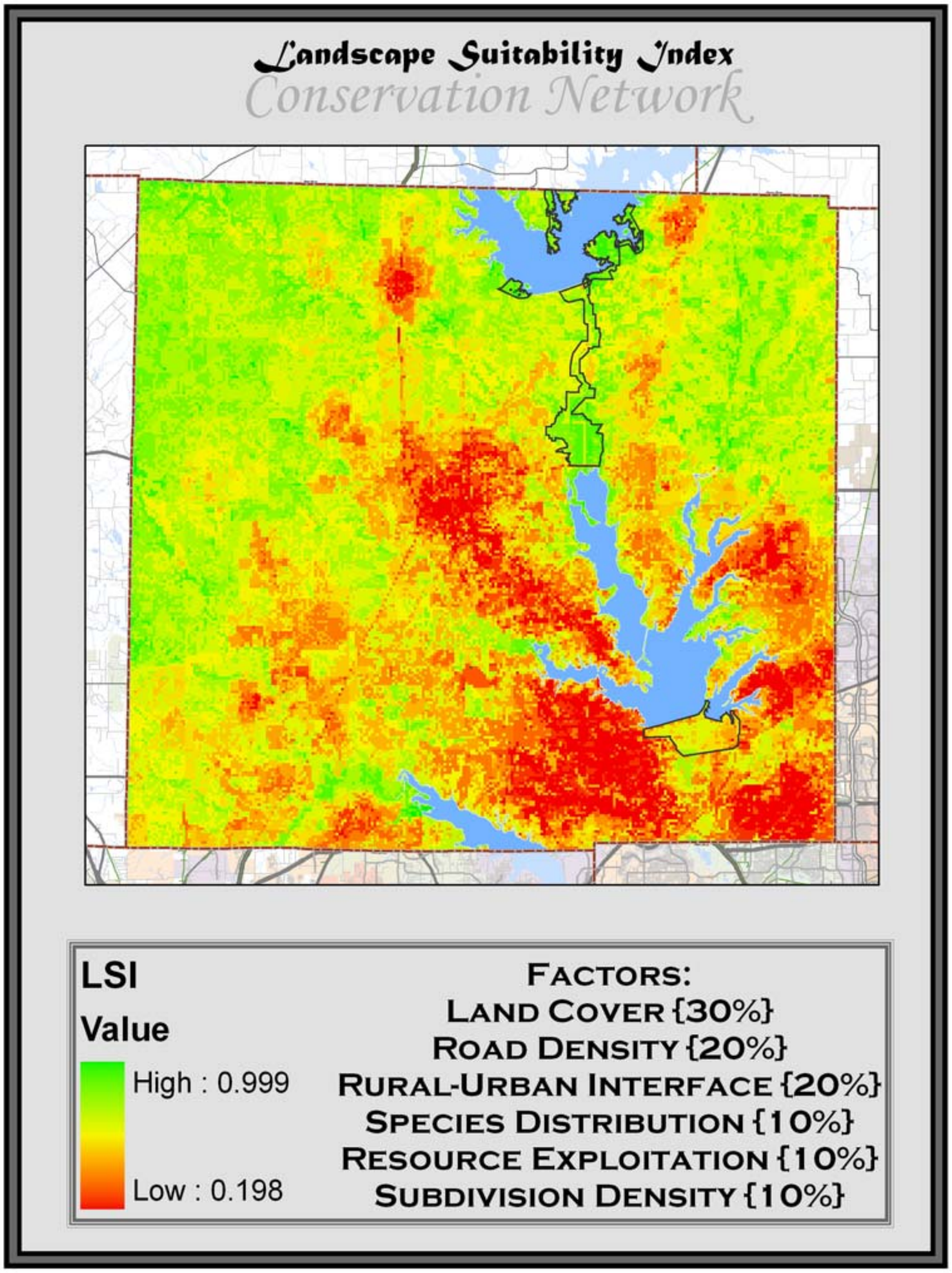


Table 8: Denton County LSI for all land within county borders.

LSI	Acres	Optimum Acres
0.19	1,125.28	213.80
0.23-0.29	22,876.39	5,947.86
0.33-0.39	32,680.61	11,765.02
0.43-0.49	55,176.13	25,381.02
0.53-0.59	81,287.13	45,520.79
0.63-0.69	141,673.39	93,504.44
0.73-0.79	143,149.20	108,793.39
0.82-0.89	70,500.58	59,925.49
0.92-0.96	13,485.02	12,675.92
1.0	938.81	938.81
Total	**562,892.54**	**364,666.54 (64.78%)**

Figure 25: Local LSI model applied to Conservation Area 1, the primary proposed FCA of this study. Area is near the Northwestern section of Denton County and currently unincorporated.

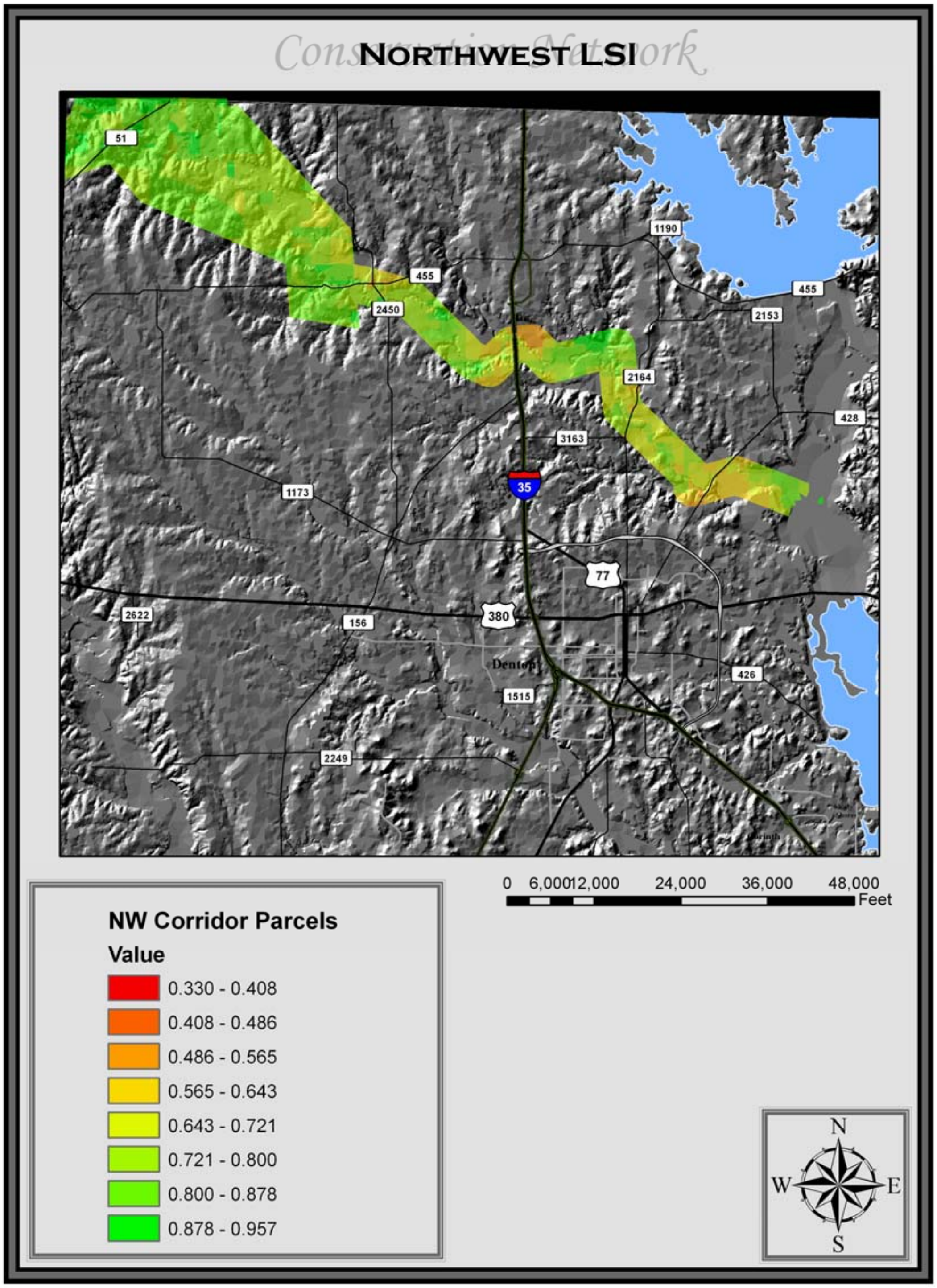


Figure 26: Local LSI values for Conservation Area 2 west of Flower Mound. Most of area was deemed unsuitable following this analysis although retains potential as potential site for additional municipal and private parks and trails.

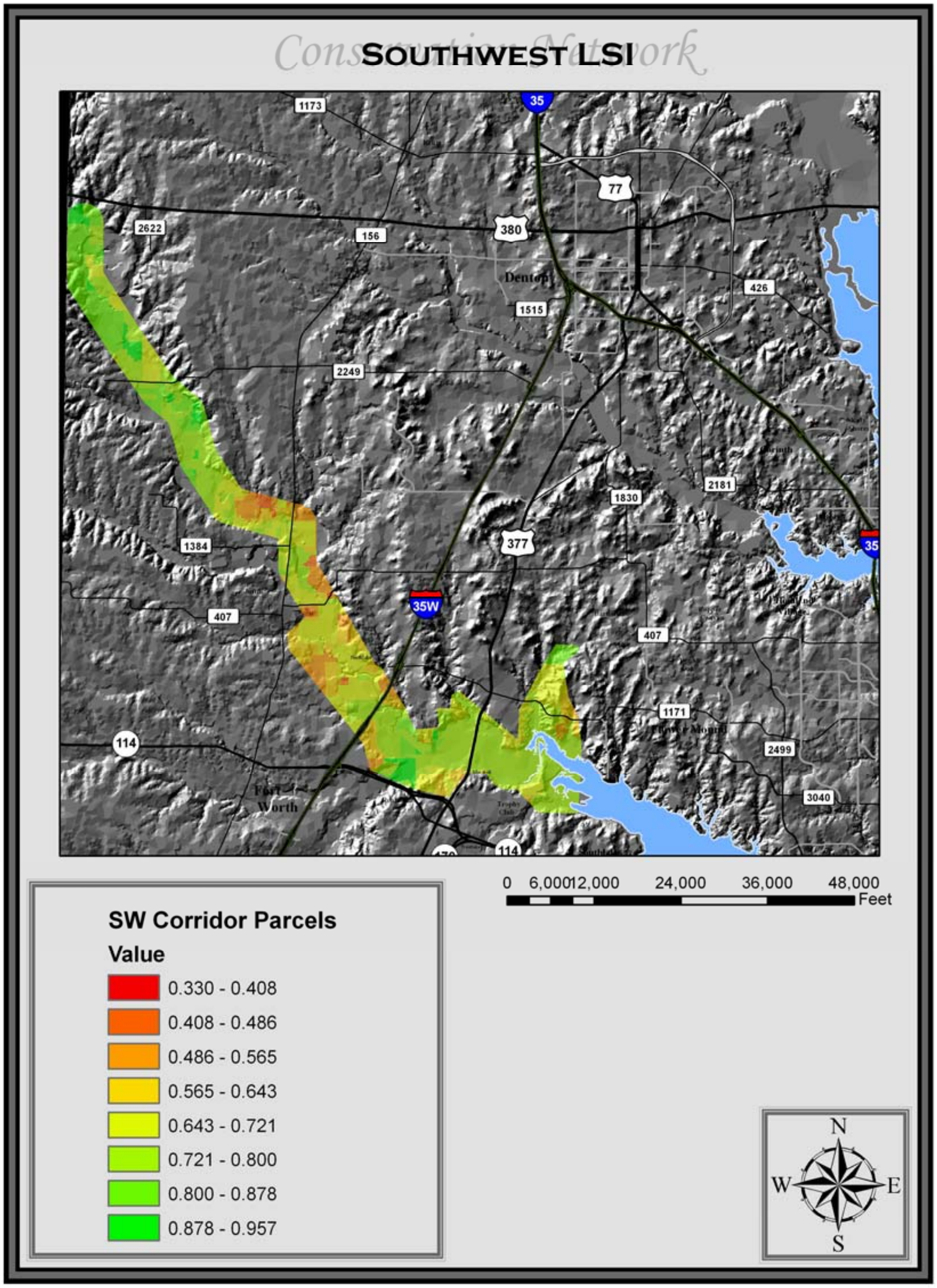


Figure 27: Composite LSI for open space. Green shades represent highest scores of the spectrum standardized to 0-1.0 scale.

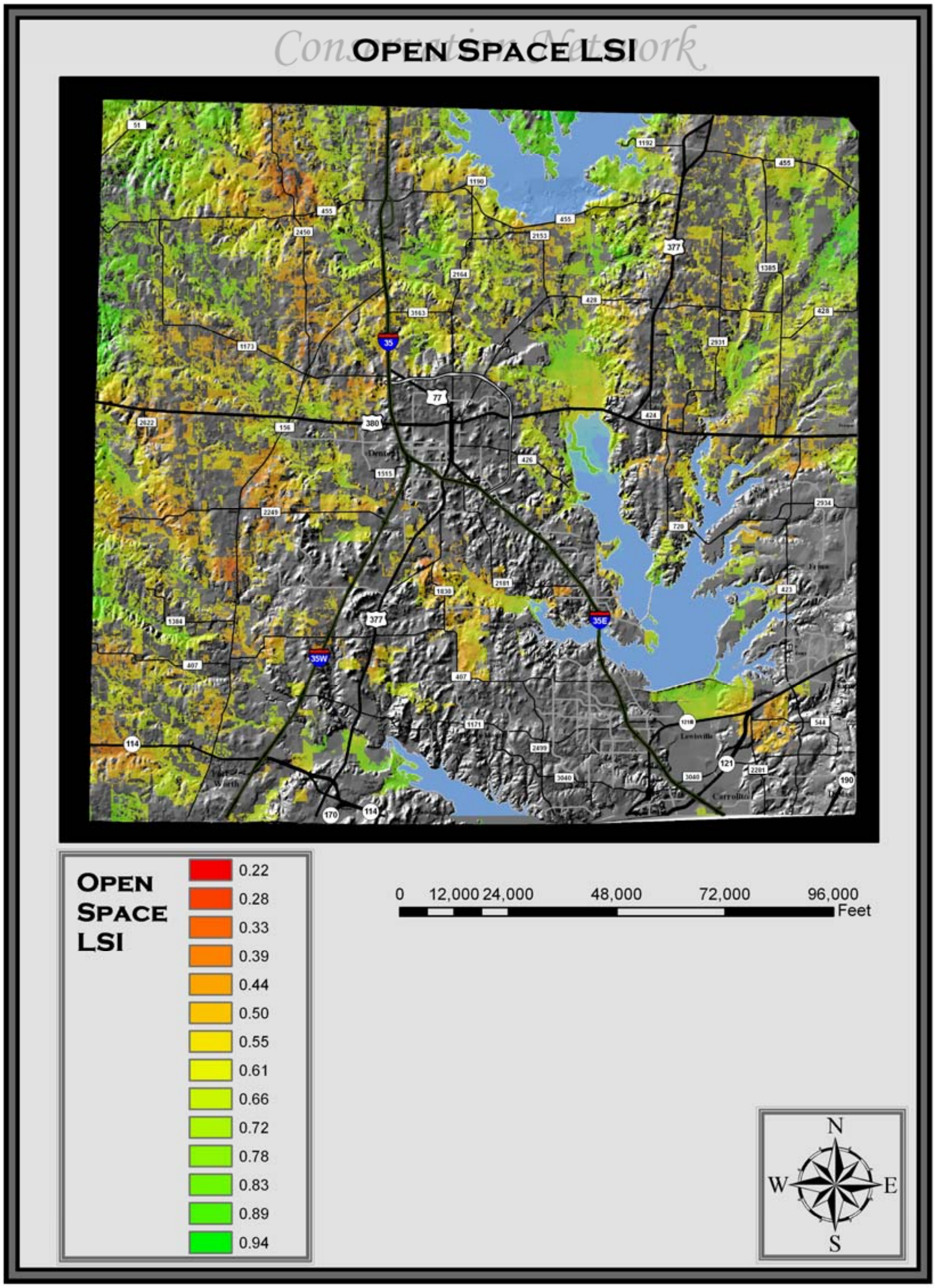


Table 9: Open Space LSI values calculated into Landscape Units.

LSI Score	Acres	Landscape Units
0.20	9.89	1.98
0.26	35.66	9.27
0.33	1,999.61	659.87
0.40	6,533.70	2,613..84
0.46	13,582.25	6,247.84
0.53	25,066.23	13,285.10
0.60	31,884.07	19,130.44
0.66	37,699.91	24,881.94
0.73	53,647.79	39,162.89
0.80	50,823.17	40,658.54
0.86	25,206.54	21,677.62
0.93	6,060.54	5,636.30
1.0	1,618.95	1,618.95
Total	**254,168.31**	**175,584.22**
Mean LSI	**0.69**	

Results for the open space LSI showed a higher consistency of mid to high range values compared to the general county LSI model due in large part to the omission of the urban-rural interface coefficient. Approximately 46% of the current open space delineated in this research was below 73% LSI which suggests 116,811 acres are either in danger of development or spatially vulnerable to development pressures. In the composite map above it can be seen that the highest concentration of impacted open space is predominantly adjacent to urban areas, most notably along the Highway 380 corridor both westward and eastwards towards the rapidly emerging subdivisions, along Interstate 35 West, and near the geographical areas west of Sanger, south of Denton along Highway 377, and near Ponder and Krum. The most geographically isolated and least impacted open space areas were primarily within the current boundaries of the Ray Roberts Greenbelt, the northwestern section of the county within the proposed

Conservation Area 1, and in the northeast section of the county east of Pilot Point and north of Celina. It is important to note here that areas of low LSI values do not imply irreparable open space but rather their degree of impact and geographical suitability as predominantly wildlife habitat. This research emphasized ecological functionality more than humanistic aesthetical functionality and thus excluded scenic views except for the historical viewsheds in favor of areas inhabited and used by wildlife. The most important features for the composite analysis were high quality habitat types and minimal presence and intensity of human impact.

Factors contributing to the composite index and lower scores can are illustrated in the coefficient maps. For example, gas and oil well density is concentrated in the Barnett Shale region in the western and northwestern sections of the county, distance to highways values high for most areas except the northwest and interior greenbelt areas, subdivision densities in the northeast, east, and southwest sections. The road density coefficient was resampled and reclassified from the county LSI to better reflect road development in open space areas exclusively but the more stringent reclassification still showed several areas of lesser impact than the other coefficients. The distance to highways coefficient was meant to counteract any imbalance or lack of representation since high volume traffic is generally associated with higher wildlife mortality than low volume and low speed roads. Nevertheless, habitat dissected by the latter roads is a primary cause of habitat loss and thus subject of serious concern. An alarming result from these coefficients, moreover, is that Denton County possesses few areas of true roadlessness, but instead features areas of low density and relative isolation. The proposed Conservation Area 1 and the Greenbelt are both circumvented by FM roads, for example, which implied that few areas could attain the highest LSI value of 1. However, open space can be highly functional within a multi-functional and fragmented landscape and deserves utmost attention as part of a comprehensive conservation network. Land production and development processes historically and presently impact the remaining open space severely enough that a comprehensive response by local governments and agencies is necessary. For instance, recent research suggests that Denton County is among the most rapidly developing counties in the nation with over 200,000 acres in the path of development (Ewing & Kostyack, 2005). If these figures are correct than the remaining open space estimated from my research would imply that only 20% of the open space analyzed is safe from such development, approximately 50,000 acres in the more remote areas of the county. Moreover, local researchers have predicted unprecedented land consumption and development near the areas most natural protected areas- the Ray Roberts Greenbelt- to exceed critical development thresholds, a prediction which as of this writing has not yet been realized thankfully (Acevedo et. al., 2002). However, the rapidly emergent subdivisions depicted previously clearly point to the urbanizing areas immediately around the area and fragmenting open space in the central and eastern portions of the county that could have been vital for expanding the greenbelt.

Solutions to counteract the loss of open space have been addressed by numerous municipalities and agencies which predominantly emphasize land acquisition, conservation easements, park designations, and bonds. The proper conservation mechanisms will ultimately depend upon each area and the municipality which possesses primary jurisdiction over it. However, most of the open space analyzed in this research is situated within unincorporated areas or within ETJ's. Both the City of Denton and Town of Flower Mound have tried to address protection of open space within their Master Plans, specifically in their Open Space Master Plans (City of Denton, 2000; Flower Mound, 2001). The Town of Flower Mound, for example, proposed three underlying protection measures: landowner stewardship, conservation development, purchase of development rights, land donations, zoning overlays, conservation easements, and incentives or regulations with emphasis placed upon valuable natural resources, community character, cultural landscapes, and agricultural lands (Flower Mound, 2001). However, the Purchase of Development Rights mentioned in the Town's Master Plan and also recommended by the NRCS previously is currently not an option in Texas, and thus remains a prospective measure not yet realized (Flower Mound, 2001). The City of Denton has formally declared similar policies towards open space protection but at the time of this writing still struggled with implementing those policies. The most notable case being recent standards held towards gas well developers that would require habitat mitigation only when 75% of the original habitat was converted, a situation which would ultimately become the burden of the landowner and not the developer once that threshold was reached (Brown, 2006).

Habitat Evaluation and Mountain Lion HSI

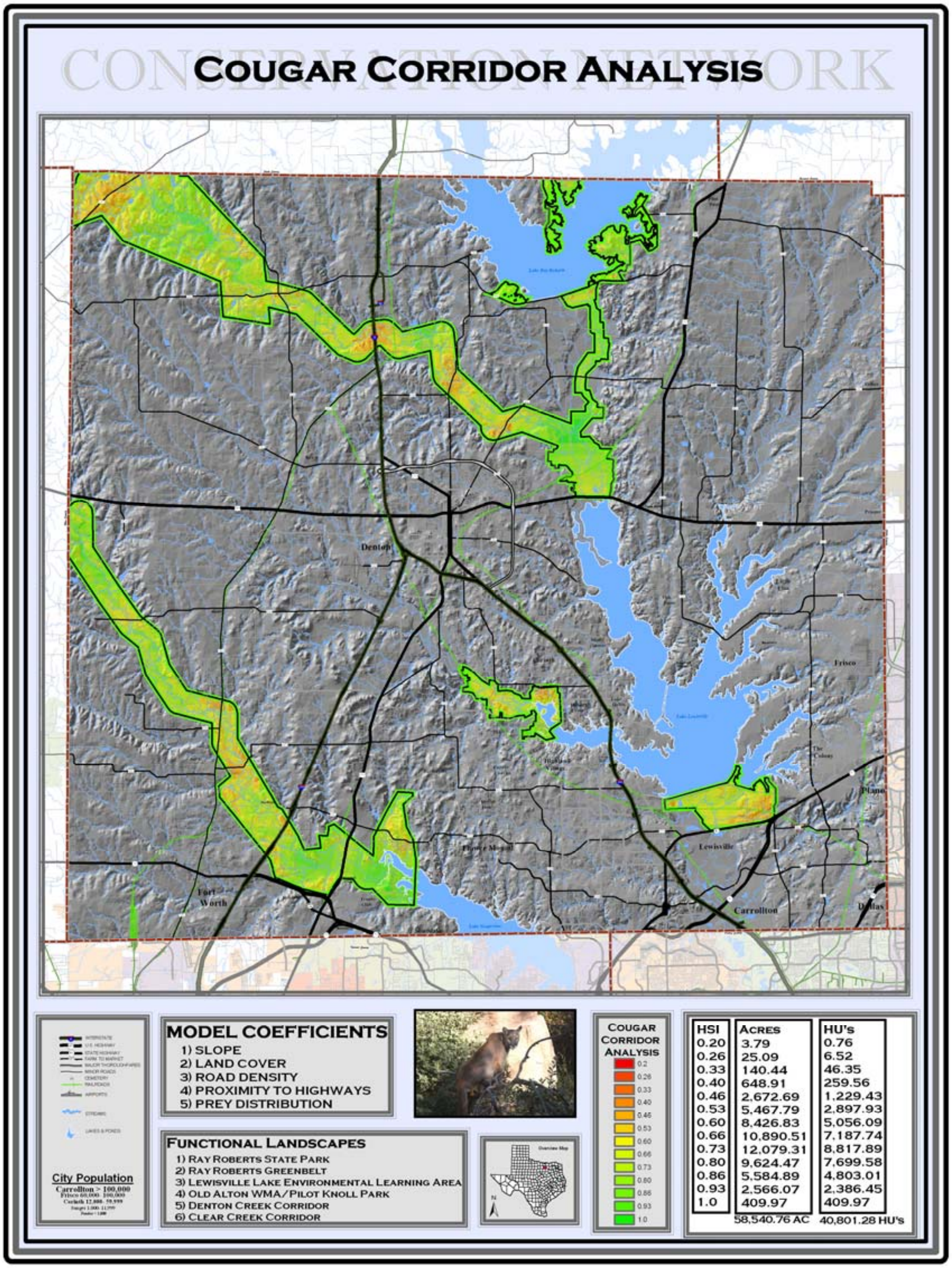
Final LSI results for the local model allowed for the selection of high priority areas for the final stage of habitat analysis. The Mountain Lion HSI was created according to the techniques and standards outlined in the Habitat Evaluation Procedures of the Ecological Services Manual, parts 101-103 (USFWS, 1980; USFWS, 1981). As mentioned in the methodology section parameters for the model changed from the local LSI to include factors most relevant to meeting the life requisites of mountain lions, including proximity to highways, distribution of its primary prey species, and topographical slope. The subsequent model was used to create an additional index that would be incorporated into a HSI model of mountain lions exclusively, and applied specifically to the available habitat within the priority conservation areas selected. Unlike the previous models the HSI converts landscape unit scores into actual Habitat Units (HU's) which act as a measure of the quantity and quality of habitat in the given study area. In this case it was applied only to those target areas meeting the general geographic suitability, and thus applied only to Conservation Areas 1 and 2, and the Northwest and Southwest Habitat Corridors as the final stage of analyzing the emergent conservation network, specifically functional properties of habitat within their respective boundaries. Although there were no encounters with mountain lions during this research numerous other species were abundant and commonly encountered.

Table 10: Wildlife Species List conducted through observation and tracking at primary research sites to verify presence or absence of indicator species.

Id	Common Name	Scientific Name	Habitat	CA1 Status	CA2 Status
1	Virginia Opossum	Didelphis virginiana	Woodlands/Wetland/Grassland	O	A
2	Nine-Banded Armadillo	Dasypus novemcinctus	Brush/Shrub/Woodlands/Grasslands	O	A
3	Eastern Cottontail	Sylvilagus floridanus	Forest/Grassland/Shrub	A	P
4	Fox Squirrel	Sciurus niger	Upland Forest/Woodland/Urban/	A	A
5	Beaver	Castor candaensis	Riparian	U	O
6	Coyote	Canis latrans	Varied/Grassland/Shrub/Urban	A	A
7	Raccoon	Procyon lotor	Riparian/Woodlands/ Brush	O	O
8	Striped Skunk	Mephitis mephitis	Woodlands/Brush/Agricultural	P	P
9	Bobcat	Felis rufus	Varied/ Thickets/Outcrops	P	P
10	White-tailed deer	Odocoileus virginianus	Forest/Grassland/Shrub/Riparian/ Agricultural	A	A
11	Red Fox	Vulpes vulpes	Forest/Grassland/Brush	P	P
12	Cougar	Felis concolor	Forest/Riparian/Brush	P	U
13	Great Blue Heron	Ardea herodias	Riparian-Lakes, Streams and Wetlands	P	O
14	Bald Eagle	Haliaeetus leucocephalus	Water/Riparian	U	P
15	Red-tailed Hawk	Buteo jamaicensis	Grassland/Shrub/Forest/Wetland	O	O
16	Great Horned Owl	Bubo virgian	Forests/Prairie/Shrub/Urban	P	P
17	Northern Bobwhite	Colinus virginianus	Grassland, Shrub, Forest Clearings, Agricultural	P	P

(O= Observed, A= Abundant, U= Uncommon, P= Probable)

Figure 28: HSI index created from composite of 5 coefficients relevant to Mountain Lion suitability. Final values were converted to standard scores from 0-1.0.



HSI	ACRES	HU's
0.20	3.79	0.76
0.26	25.09	6.52
0.33	140.44	46.35
0.40	648.91	259.56
0.46	2,672.69	1,229.43
0.53	5,467.79	2,897.93
0.60	8,426.83	5,056.09
0.66	10,890.51	7,187.74
0.73	12,079.31	8,817.89
0.80	9,624.47	7,699.58
0.86	5,584.89	4,803.01
0.93	2,566.07	2,386.45
1.0	409.97	409.97
	58,540.76 AC	40,801.28 HU's

Figure 29: Northwest Study Area Mountain Lion HSI.

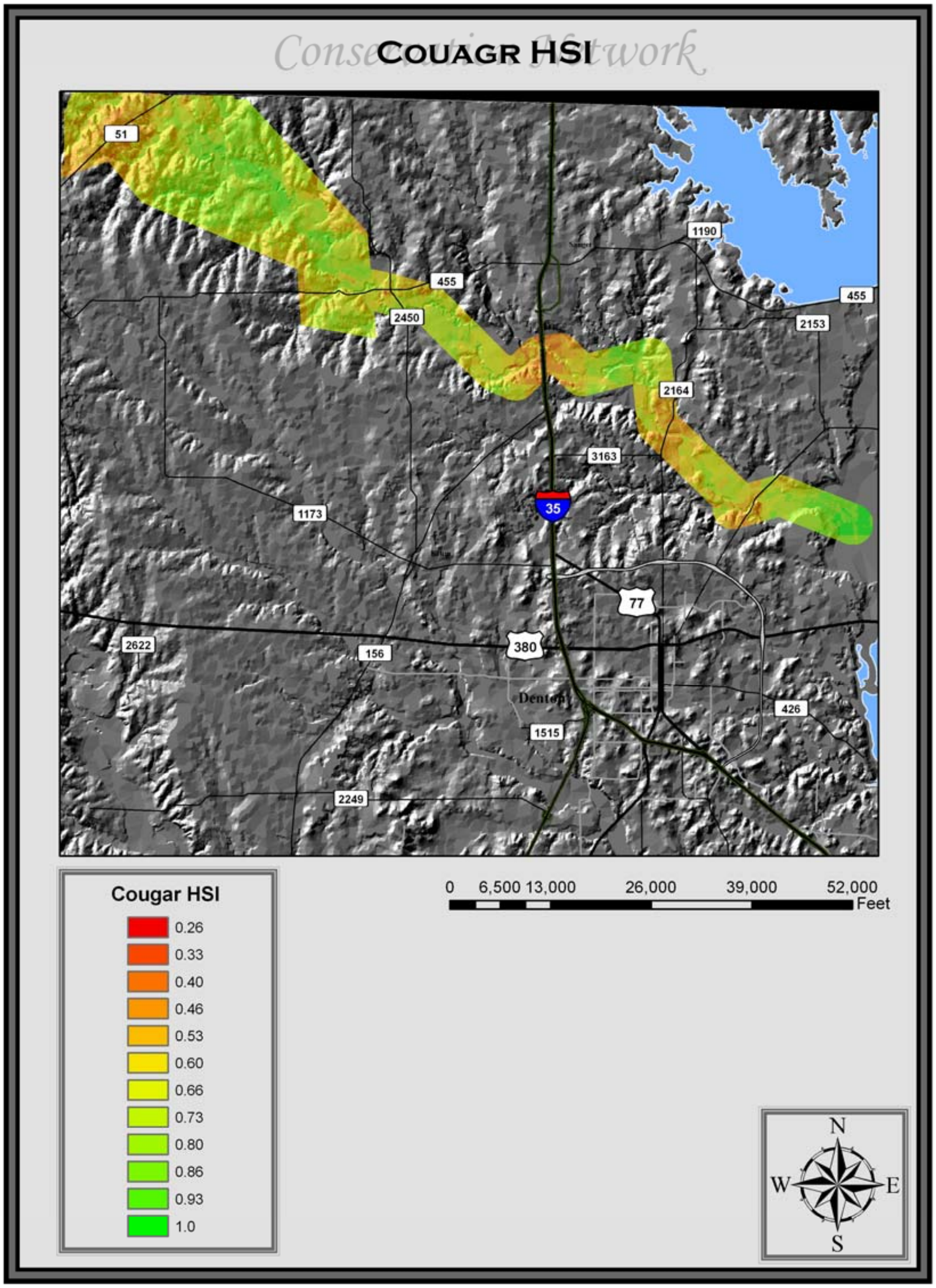


Figure 30: Southwest Study Area Mountain Lion HSI.

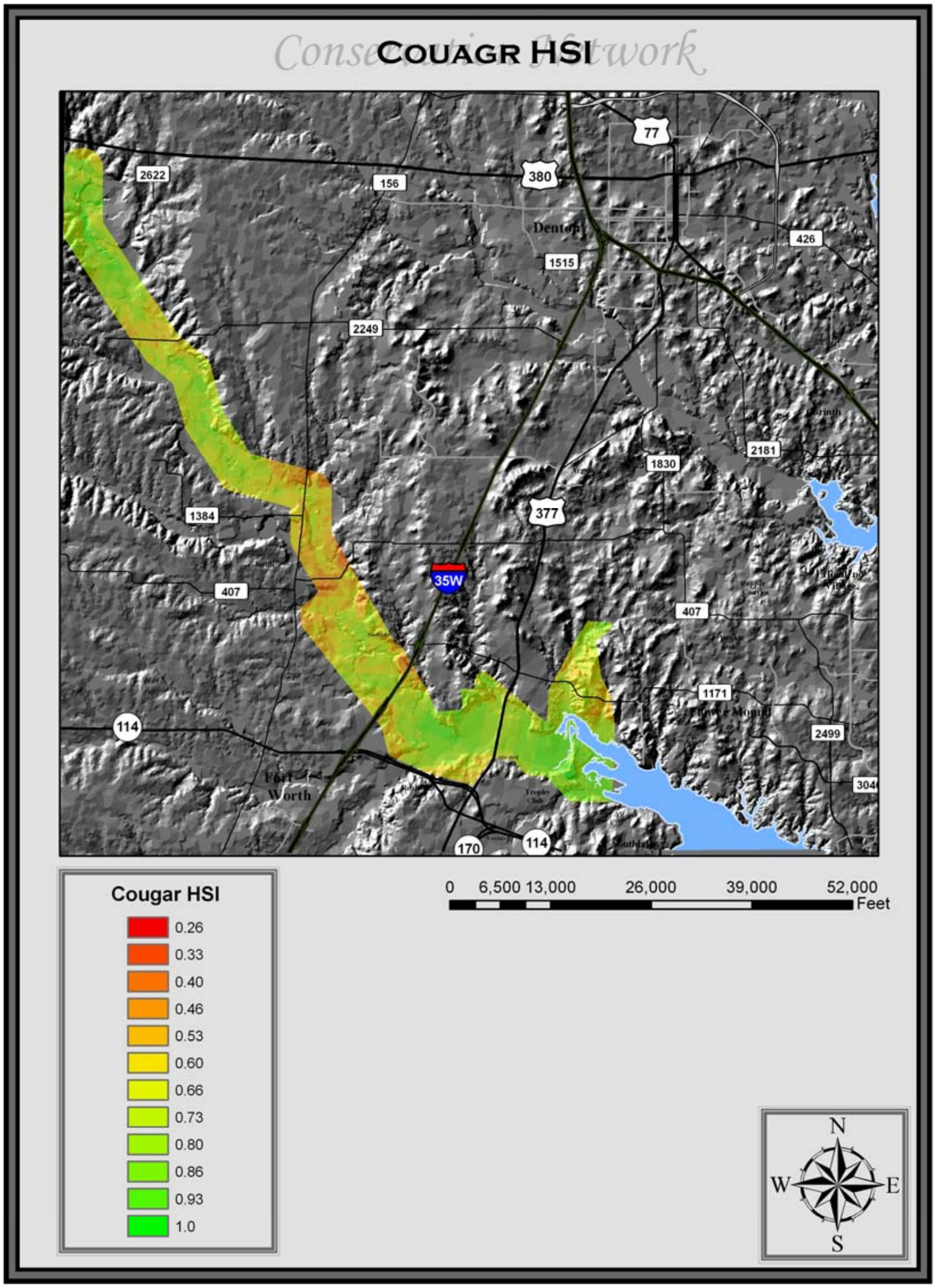


Table 11: Mountain Lion Corridor results. All HSI scores converted from actual acres to optimum acres.

HIS	Acres	Optimum Acres
0.20	3.79	0.76
0.26	25.09	6.52
0.33	140.44	46.35
0.40	648.91	259.56
0.46	2,672.69	1,229.43
0.53	5,467.79	2,897.93
0.60	8,426.83	5,056.09
0.66	10,890.51	7,187.74
0.73	12,079.31	8,817.89
0.80	9,624.47	7,699.58
0.86	5,584.89	4,803.01
0.93	2,566.07	2,386.45
1.0	409.97	409.97
Total	58,540.76	40,801.28

The Mountain Lion Corridor Model was applied specifically for the conservation network delineated by both FCA's and corridors with the inclusion of Ray Roberts State Park and Greenbelt, LLELA, and Pilot Knoll Wildlife Management Area. Within this analysis mask approximately 58,540.76 acres of habitat was assessed qualitatively and quantitatively to determine the overall suitability. As seen in the preceeding map the core areas received high scores (shades of green) while the interior of the northwest and southwest corridors, the upper reaches of the Ray Roberts Greenbelt, and portions of both Pilot Knoll WMA and LLELA, each hinted to increased vulnerability. After the HSI index was applied to the conservation network mask and calculated for HU’s the total area produced 40,801.28 acres of optimum habitat within the network mask exclusively. Additional tests of the county and rural landscape were used to determine other areas where corridor movement was suitable and probable. The rural landscape resulted in approximately 252,755 acres of optimum land according to the Mountain Lion Model.

Table 12: Habitat Units for FCA 1 & Northwest Corridor, and FCA 2 & Southwest Corridor.

	Upland Forest	Riparian Forest	Shrub	Grassland	Wetland	Range	Total
FCA 1	1,684		474	2,463	26	2,310	6,957
NW Corridor	1,340	279	484	637	50	2,049	4,839
FCA 2	269	3,387	851	275	210	1,415	6,407
SW Corridor	1,237	2,395	661	161	102	1,849	6,405

HSI scores for CA 1 habitat types showed that the majority of the area falls in the mid to high range suitability. The majority of upland forest HSI values were above 60% with approximately 1,684 acres of HU's. Grassland and Range HS were predominantly above 53% with 2,463 and 2,310 HU's respectively, indicative of the dominance of grassland and range land cover in the landscape matrix. Meanwhile, shrub HSI values were generally over 53% but only account for 474 HU's. Finally, wetland HSI values were primarily above 60% but limited to 25 HU's throughout the micro study area. The overall HU's suggest that the grassland-forest matrix would be sufficient for numerous species, including white-tailed deer and other prey species, but near the minimum threshold for establishing a range by dispersing mountain lions. Their resource range would be restricted to the forest and forest-grassland edges.

HSI values for the Northwest Corridor indicate that the overall habitat value of the landscape spanning from the Ray Roberts Greenbelt to the Northwestern section of the county are highly suitable as a whole but also highly fragmented near rural communities and Interstate 35. Upland forest HSI values were predominantly over 60% with a total of 1,340 HU's, and additional 650 HU's from Conservation Area 1 as the corridor extends eastwards. As the corridor nears the greenbelt in particular riparian forest HSI values were predominantly above 73% with an additional 278 HU's added to the forest land cover total. Range land cover, the second largest habitat type in the corridor but the least suitable for wildlife, was primarily above 53% with 2,048 HU's. The majority of grassland HSI values were above 60% but account for only 637 HU's when assessed separate from CA 1's boundaries. Shrub HSI values were primarily above 60% but account for only 484 HU's. Meanwhile, wetland habitat increases along the corridor as it runs eastward. The majority of wetland HSI values were over 60% with approximately 50 HU's along the entire Northwest Habitat Corridor. The corridor may show greater potential for supporting a wider range of resources as a function of increased space yet at the cost of increased fragmentation as it runs through rural communities and major roads. Yet in order to support a mountain lion population and its resource base both the Conservation Area 1 and Northwest Habitat Corridor would need to be protected from further development and resource exploitation to be supportive. If the entire landscape incorporating these two study areas could be protected through land acquisitions, conservation easements, and environmentally-sensitive planning by all affected municipalities then it would substantially improve the natural and ecological quality of the existing conservation network.

The total HU's for FCA 2 are 6,418.48 with an optimum of 5,003.86 HU's of natural to semi-natural habitat. The largest totals were from riparian forest, shrub, and wetland which are the predominant habitat types in the core area of Denton Creek's natural habitat. Both upland forest and grassland HU's were considerably lower with range and pasture comprising of 6,418.49 HU's primarily in adjacent patches with some interspersion at the core's edge. Upland forest HSI scores were primarily in the 0.60-0.86 range but only resulted in 269.09 HU's. In stark contrast, riparian forest values generally fell into the 0.66-0.93 HSI range resulting in 3,387.29 HU's of predominantly Cottonwood and Willow species. Most of the interior riparian forest stretching from the borders of Grapevine Lake to Interstate 35-W are fairly cohesive and undisturbed apart from some minor roads, recreation, and residences. Moreover, white-tailed deer, foxes, and other wildlife appeared to be most abundant in this core area following Denton and Elizabeth Creeks. Shrub HSI scores predominantly fell into the 0.60-0.93 range with 881.85 HU's, offering a substantial amount of mixed vegetation and brush for resource areas and corridor movement. Grassland HSI scores were in the lower range at 0.53-0.86 with a total of 275.18 HU's of mostly disturbed or vulnerable grassland vegetation, although red-tailed hawks and small rodents appear to be abundant in these areas. Wetland HSI scores fell into the 0.66-0.93 range with a total of 210.45 HU's concentrated near Grapevine Lake. Great Blue Heron were observed in this area on several occasions during site visits, suggesting that wetland habitat at the confluence of Denton Creek and Grapevine Lake is largely functional and utilized. Moreover, white-tailed deer tracks were observed along the wetland's edge and appeared to cross thru the wetland with intercrossing deer trails. And, finally, range and pasture HSI scores were lower than average with the majority falling into the 0.53-0.86 range and resulting in 1,414.63 HU's of potential habitat within FCA 2 which could play a functional or structural role for wildlife usage. However, most of the range in this area, and in the county, is predominantly utilized by livestock and most often inhabited by smaller mammals and avian species. Range within FCA 2 boundaries generally lay at the outer edges and near roads and residences which add to their marginal use by wildlife.

The Southwest Corridor which runs along the general boundaries of Denton Creek and its tributaries comprises of 6,407.24 HU's of which 4,558.22 are primary natural or semi-natural areas. A large portion of the corridor is highly fragmented as it extends westwards and northwards from I-35 W which resulted in lower HSI scores and HU's than the core FCA 2. However, the corridor includes a substantial increase of upland forest as it extends upwards topographically. Upland forest HSI scores fell into the range of 0.66- 0.93 with a total of 1,237.33 HU's in contrast to 269.09 HU's of upland forest in FCA 2 alone. However, riparian forest decreases in the corridor when assessed exclusively with only 2,395.61 HU's primarily falling into the 0.73-0.93 HSI range. Shrub HSI scores were predominantly in the 0.66-0.93 range with 661.28 HU's, also a decrease in size from FCA 2 with the corridor's constricted boundaries. Grassland HSI scores were predominantly in the 0.60-0.86 range with a total of 161.01 HU's of mostly disturbed or vulnerable grassland habitat. Wetland HSI scores fell into the 0.66-0.93 range with a total of 102.99 HU's, also a decrease with the arbitrary boundaries drawn for the Southwest Corridor. Meanwhile, range and pasture increase along the corridor with a total of 1,849.02 HU's falling into the 0.60-0.86 HSI range. Moreover, as the corridor extends west and north from FCA 2 it crosses through an increasingly fragmented landscape where urban and agricultural land cover types are more abundant or comparable to natural habitat in several areas. Potential cougar movement through this corridor appears to be significantly more vulnerable and less suitable in contrast to the Northwest Corridor along Clear Creek's watershed. However, the value of FCA 2 and its rich habitat is very important for a potential conservation network, and thus its connectivity to the Southwest Corridor cannot be understated nor dismissed all together.

Table 12: Mean HSI scores per habitat type and Conservation Area

	FCA 1	Northwest Corridor	FCA 2	Southwest Corridor
Upland Forest	79	77	71	79
Riparian Forest	NA	91.5	81	81
Shrub	74	76	78	79
Grassland	70	69	68	74
Wetland	79	80	83	81
Range	70	70	70	72

After the assessment of each study area exclusively it became apparent that each area, when treated alone, was insufficient in size to encompass a suitable home range for mountain lions but generally sufficient for most other species who have adapted well to human presence. Although the presence of mountain lions in Denton County is faint compared to most other species and indeed less common the total network of functional landscapes and places beholds potential to offer sanctuaries to one of the remaining large predators. When taken as a whole, for example, the proposed network comprises of nearly 58, 540.76 acres with a total of 40,801.28 suitable landscape units would offer a more cohesive and supportive resource base for transient and resident wildlife. More specifically, this would help meet the need for transient mountain lions who come through Denton County and perhaps allow for the establishment of a small population to safely utilize- both for themselves and for people- the Denton Creek and Clear Creek corridors. Most sightings have been within reach of both corridors and may point to the necessity of more aggressive habitat protection in these two areas to offer them more habitat and to offer ourselves and greater border to prevent their intrusion into residential areas as has been increasingly common in the western states. The network treated as whole, for example, is sufficient in size and geographical scope for female mountain lions and at least one resident male (McKinney, 2003). Although this assessment was spatially limited to cohesive functional landscapes and places the total rural landscape of Denton County includes roughly 300,000 acres of lower population density and agricultural-natural land cover types, including the study areas of this assessment. Several important places have been omitted from this study which would contribute to the conservation network, and where some mountain lion sightings have occurred, such as the Rainbow Valley Co-Op near Sanger and Pilot Knoll Park adjacent to Lewisville Lake but near urban and residential areas. For the purposes of this research it became apparent after the corridor analysis that FCA 1 and the Northwest Corridor must be treated as a cohesive whole, and likewise FCA 2 and the Southwest Corridor, in order to meet the predicted demands of a sufficient resource base and suitable corridor movement. The initial study areas, therefore, are part and parcel of a broader, county-wide landscape that must be conserved and protected.

Figure 31: Primary road underpasses intersecting FCA #1 and the Northwest Corridor proved to be navigable during field studies. Presence of deer tracks, and several signs of medium-sized mammals present near underpass.

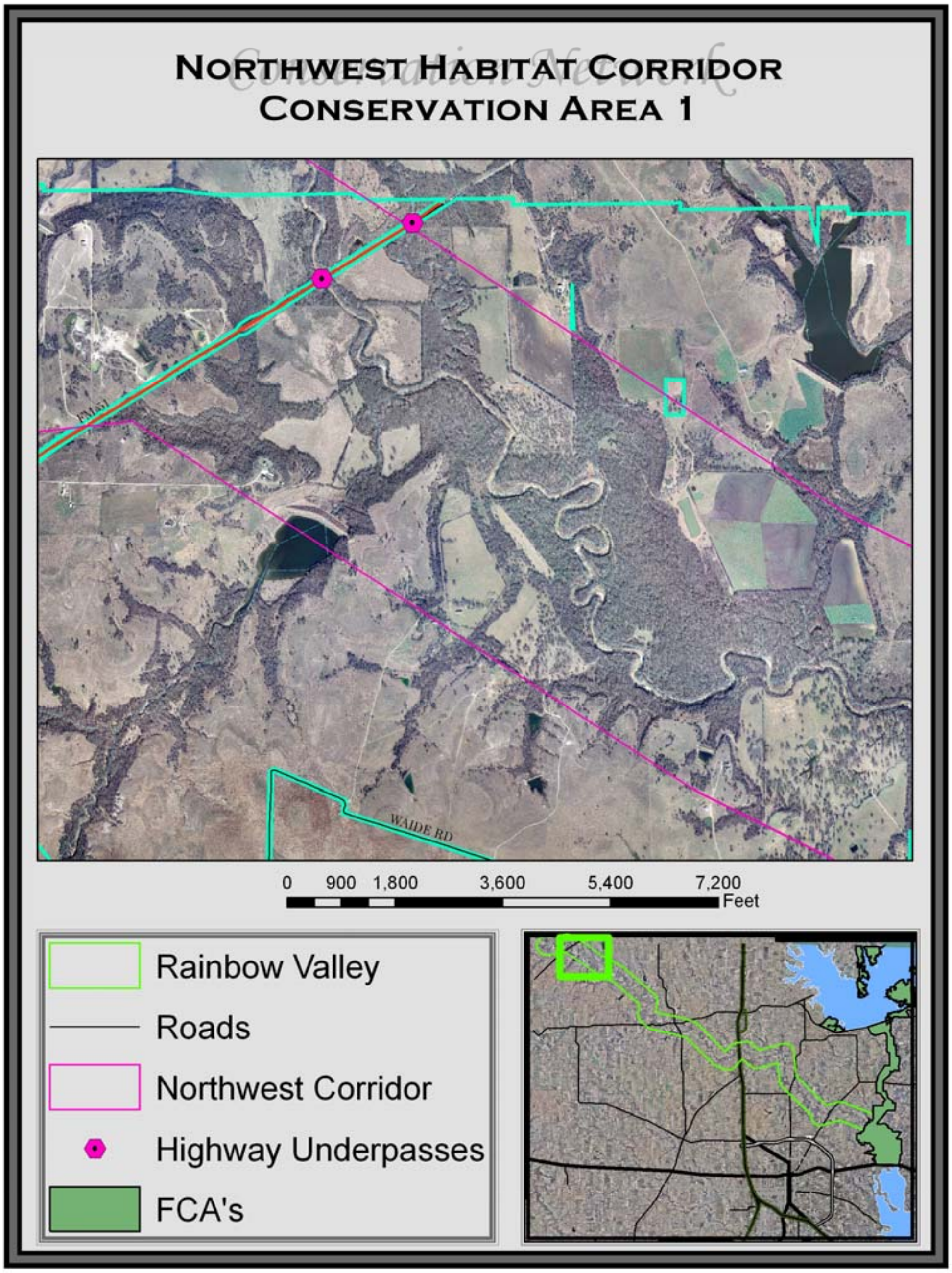


Figure 32: Primary road undrpasses along FM 2450 and FM 455 proved to be navigable during field studies southeast of FCA #1.

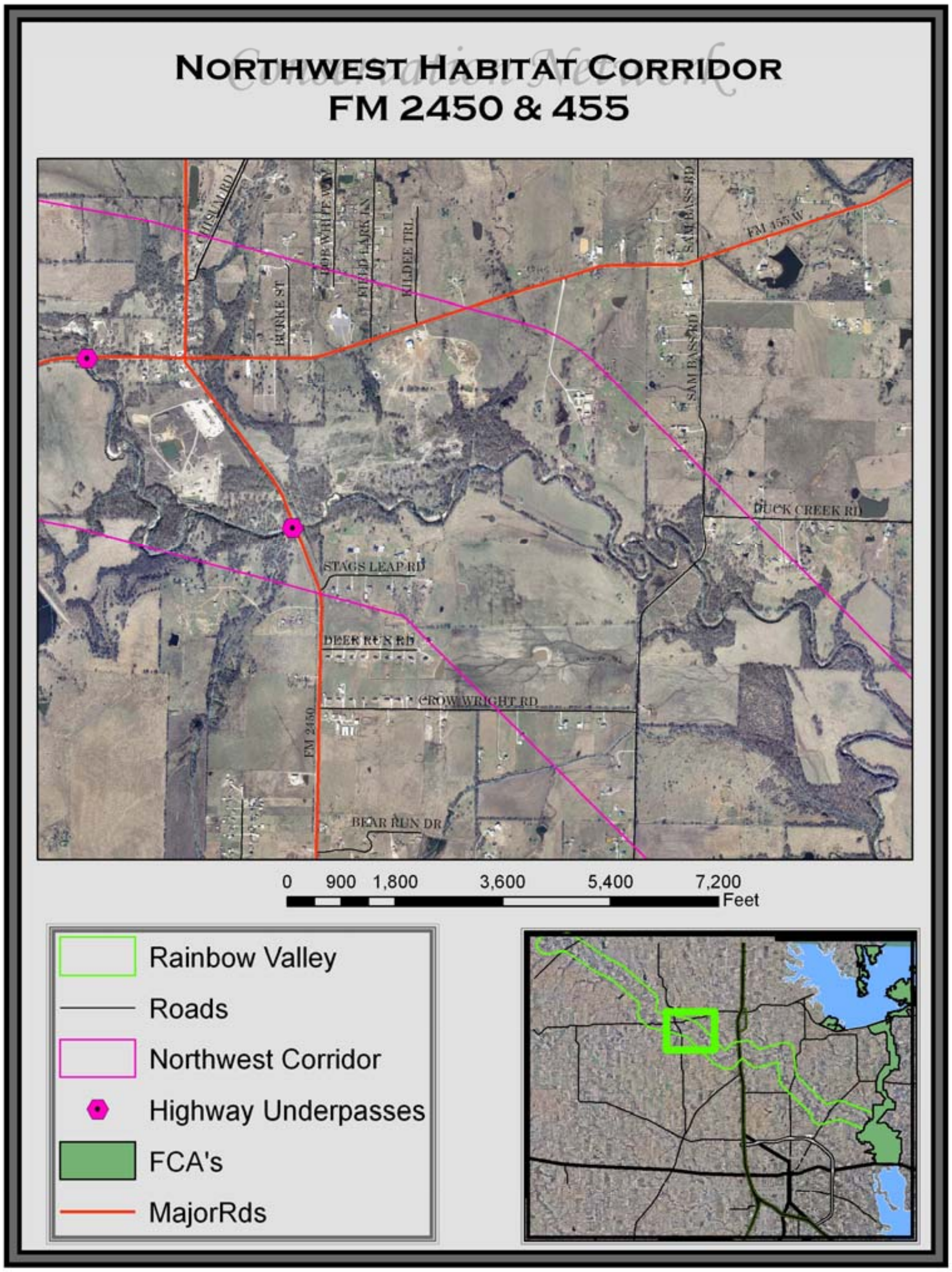


Figure 33: Primary road underpasses near Sanger showed connectivity between western and eastern areas of I-35, one of the few functional underpasses along the busiest interstate in the county.

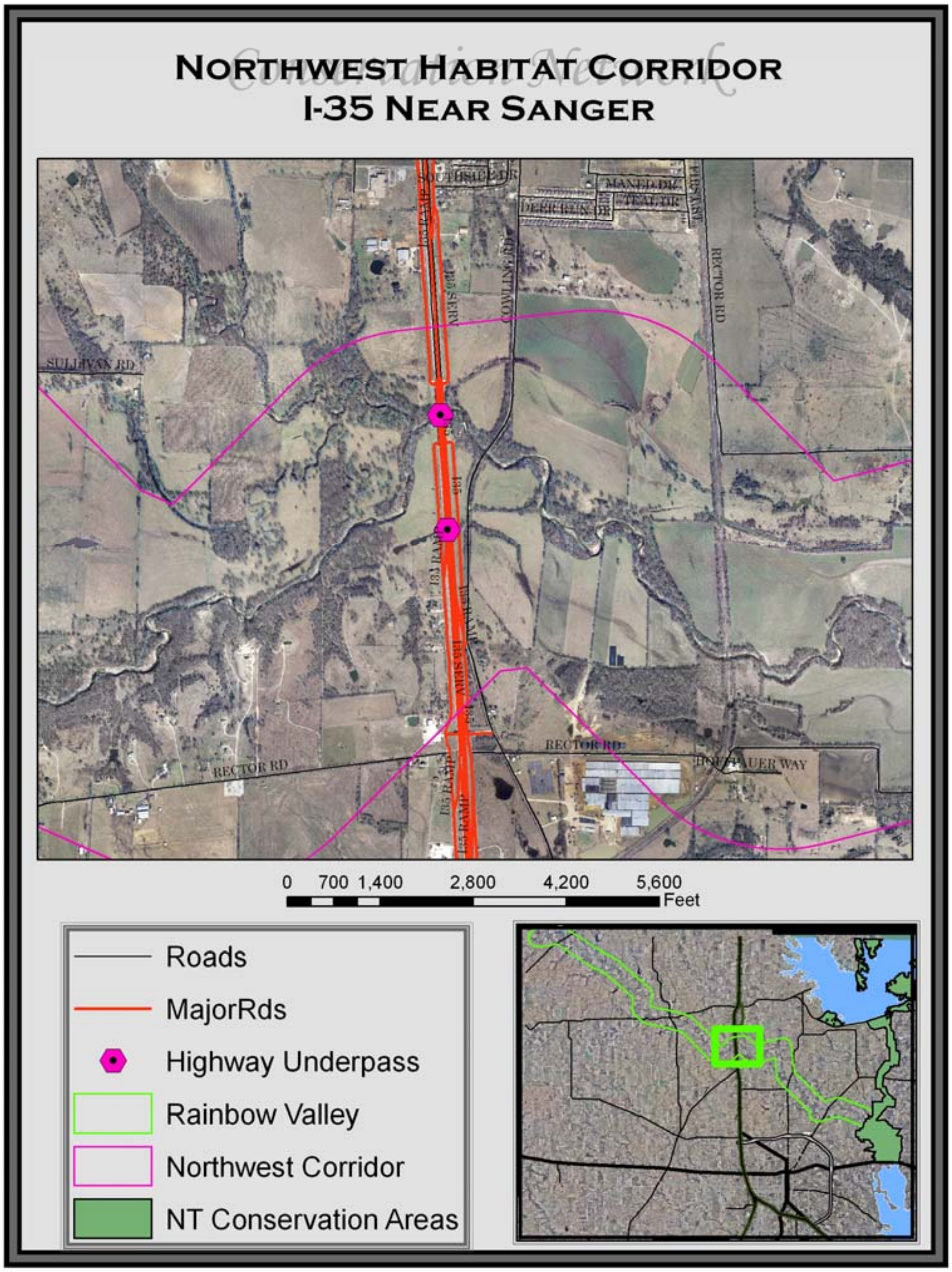


Figure 34: Road underpass at FM 2164 functioning as the last major barrier in connecting to the Ray Roberts Greenbelt. The underpass was verified as navigable during field studies.

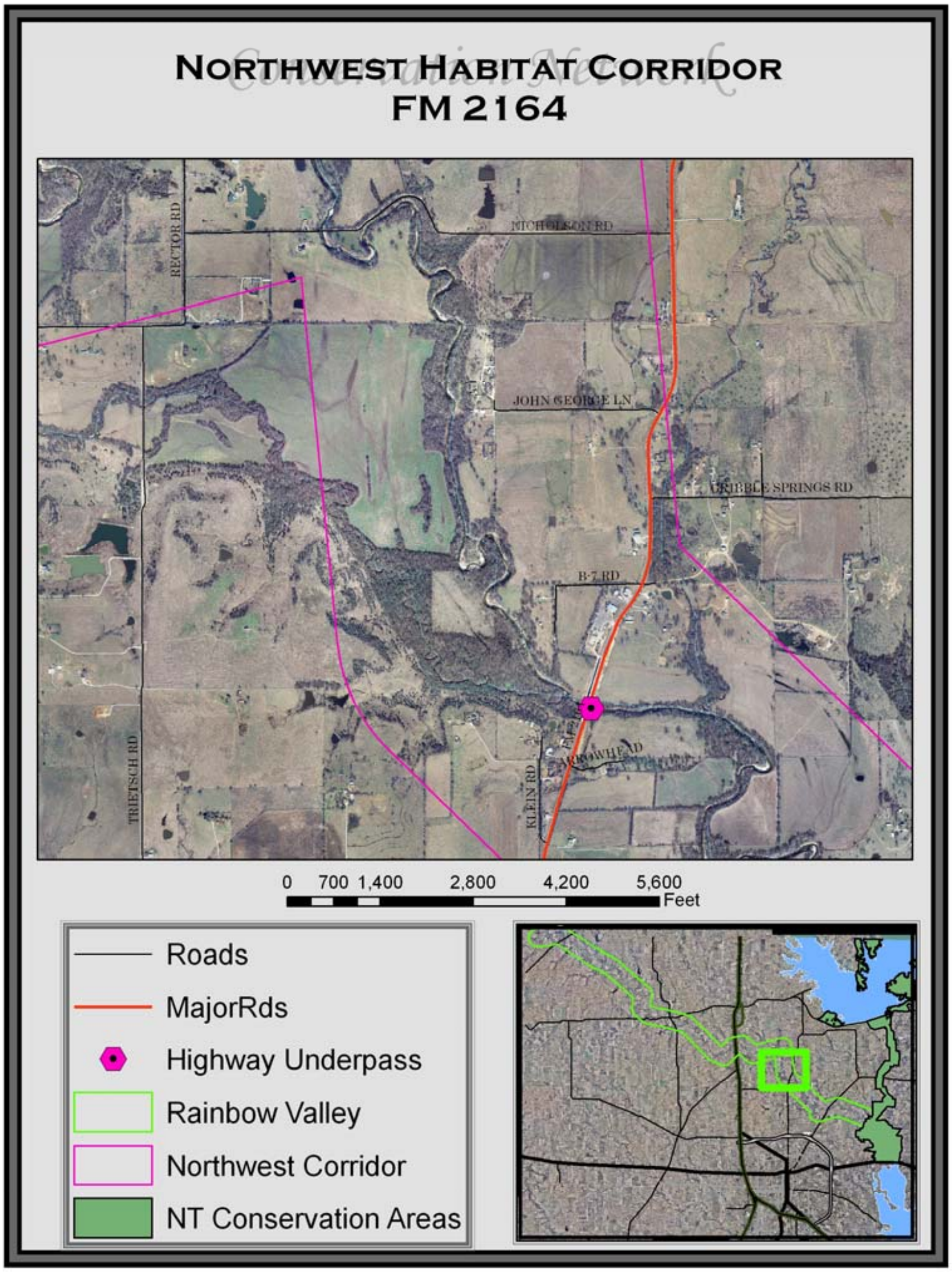


Figure 35: Westernmost extension of the Southwest Corridor at FM 2449 contains navigable road underpass. Area may be the most suitable section of the corridor for conservation purposes considering its distance from nearby municipal areas.

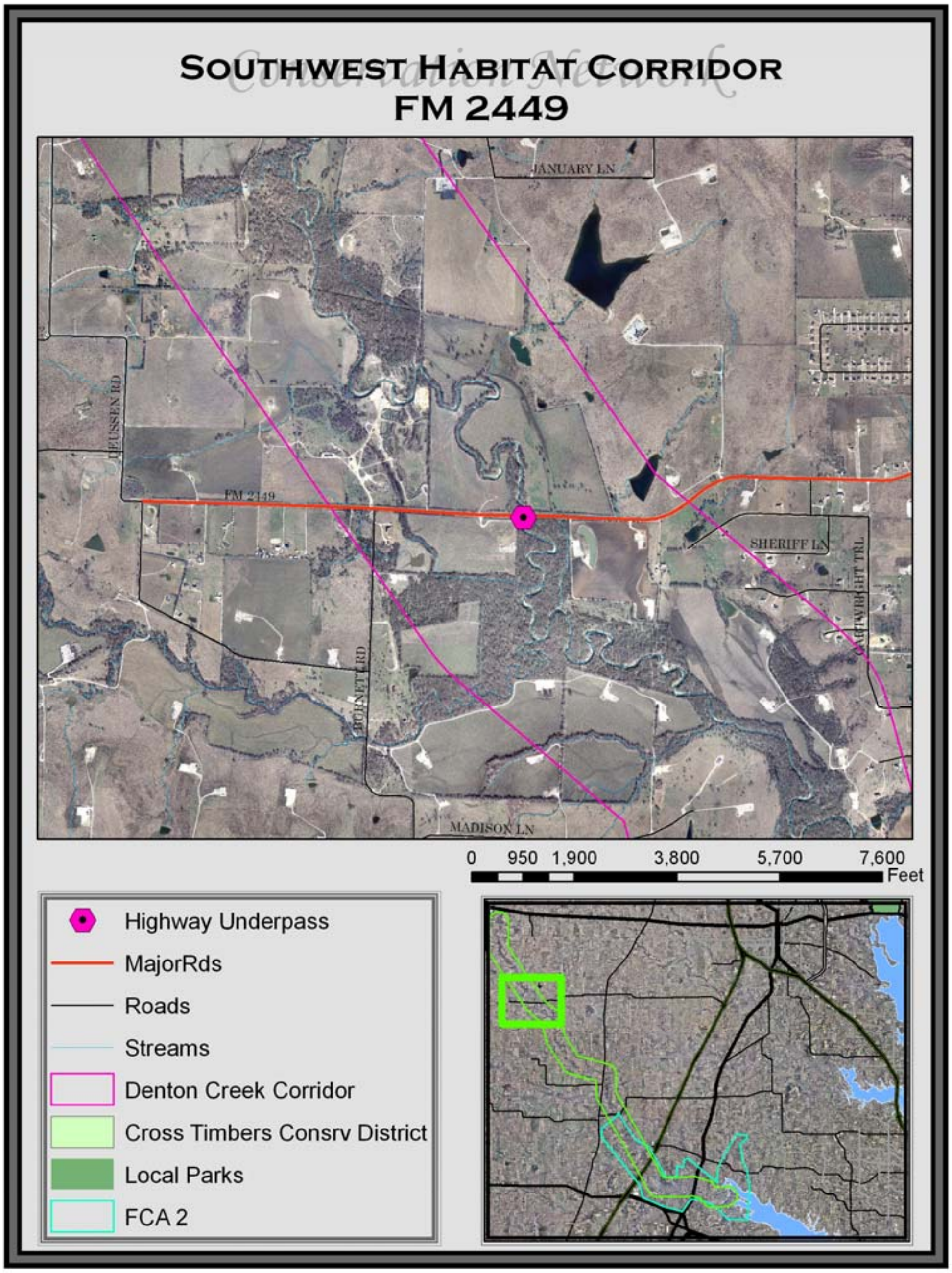


Figure 36: Road underpasses at FM 156 and FM 1384 to show continued connectivity of the Southwest Corridor. However, this area marks increased proximity to urban areas and a highly fragmented landscape.

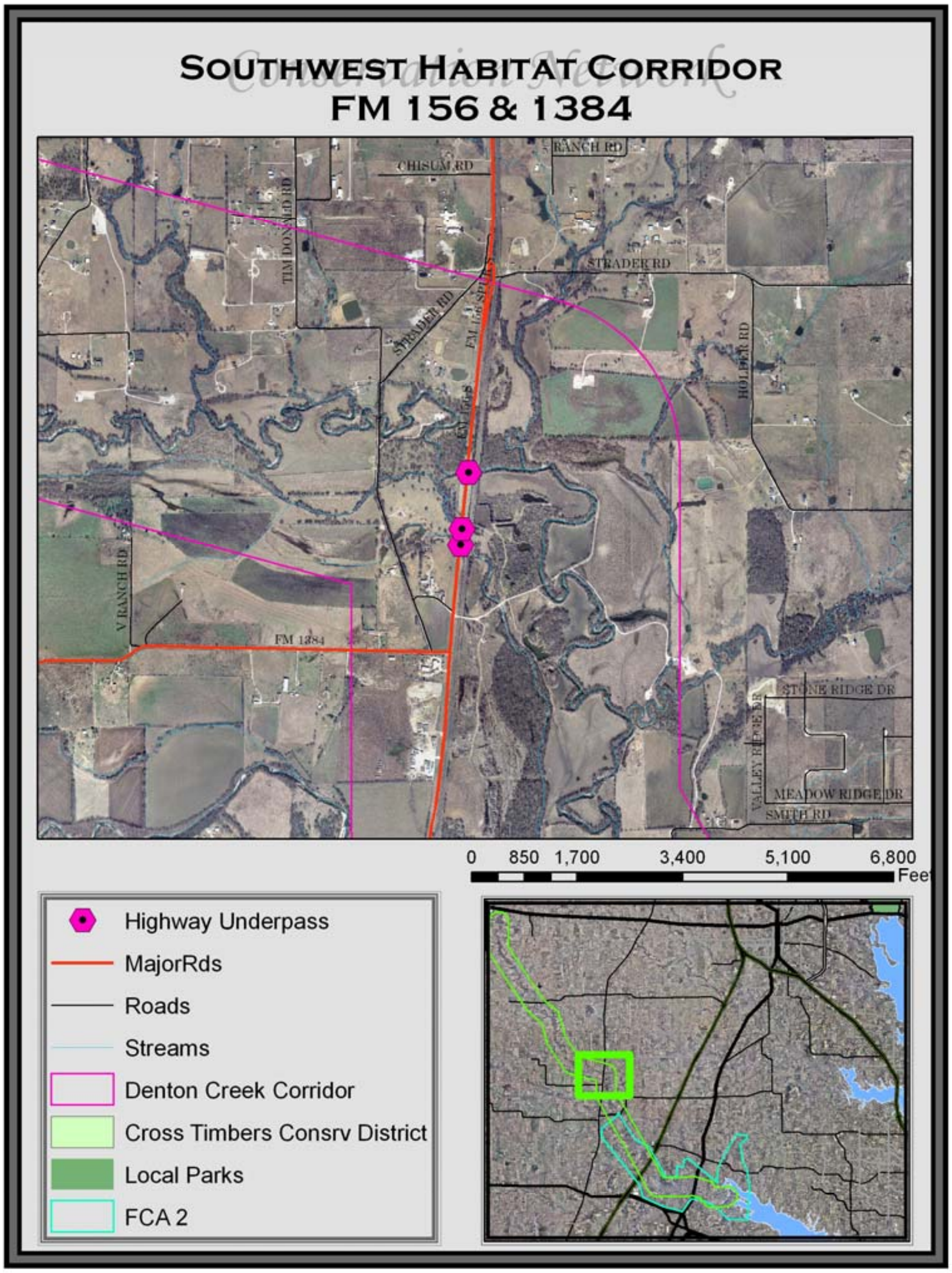


Figure 37: Road underpass at FM 407 proved to be only safe migration route from areas west of FM 407 to habitat to the east.

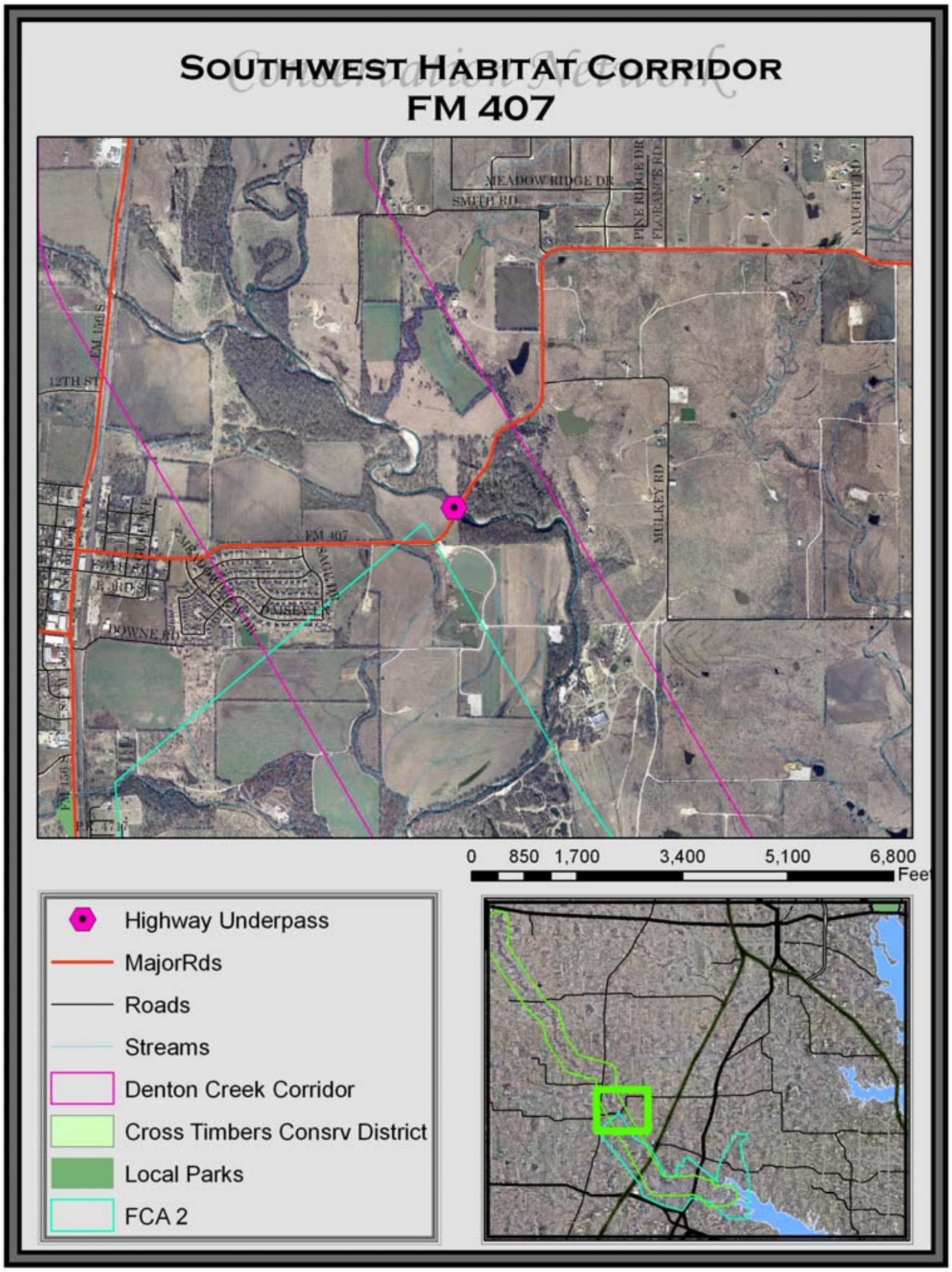


Figure 38: Road underpasses along I-35 are both navigable and highly scenic. It contains some of the most intact habitat along the corridor in spite of its surrounding landscape.

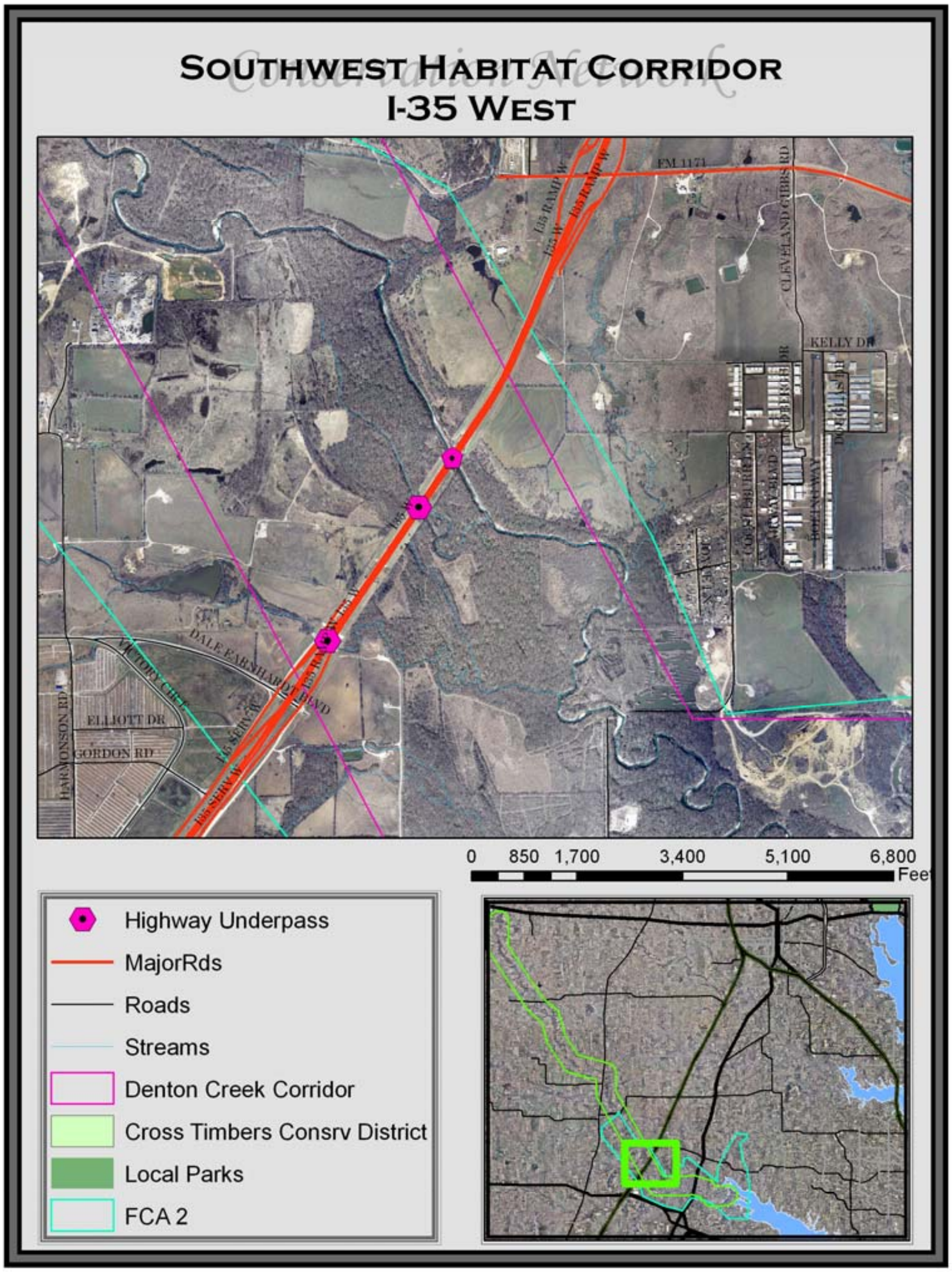


Figure 39: Road underpass at Highway 377 as the last major barrier within the Southwest Corridor. Underpass proved navigable suggesting functional connectivity of the entire corridor.

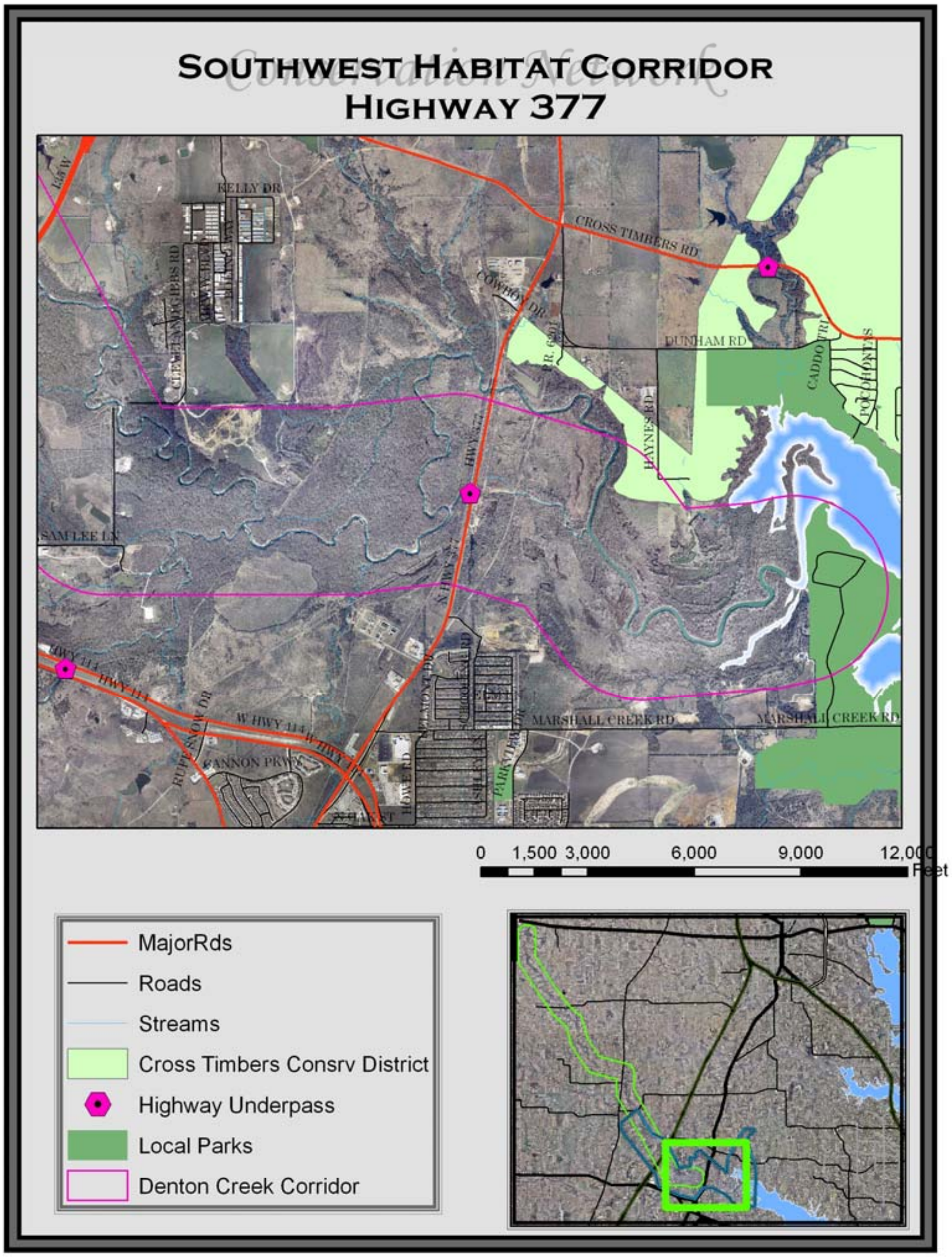


Table 13: Overall rating and suitability of highway underpasses along habitat corridors.

	Land Cover	**Permeability**	**Wildlife**
FM 51	**Forest/Shrub**	**Yes**	**Abundant**
FM 2450/455	**Ag/Forest**	**Yes**	**Common**
I-35	**Ag/Forest**	**Yes**	**Limited**
FM 2164	**Ag/ Thin Forest**	**Yes**	**Limited**
FM 2449	**Ag/Patchy Forest**	**Yes**	**Common**
FM 156/1384	**Ag/Patchy Forest**	**Yes**	**Limited**
FM 407	**Ag/Patchy Forest**	**Yes**	**Limited**
I-35 W	**Interior Forest/Urban/Ag**	**Yes**	**Common**
HWY 377	**Woodland**	**Yes**	**Abundant**

The above maps of all road underpasses show the level of habitat quantity and degree of habitat fragmentation essentially to provide a walkthrough of each corridor. Site visits were made to core areas during the early phases of this research but over the course of three years the entire corridors were assessed on foot, and each underpass assessed for its overall quality and the presence of wildlife. Only the FM 51 and HWY 377 underpasses seemed to be areas where abundant wildlife was possible with the presence of more tracks (white-tailed deer, raccoon, and bobcat) and with an increase in sightings. Several coyotes were encountered during the field studies in addition to red-tailed hawks and deer. The proceeding photographs are included to add more visual clarity to these underpasses and their significance to wildlife migration and movement.

CHAPTER VI

CONCLUSIONS AND DISCUSSION

With the original quest to determine the suitability of Denton County's landscapes and wildlife corridors for conservation design and wildlife protection results from each of the GIS models and site visits to each of the study areas showed overall positive results for the remaining quantity and quality of the county's landscape as a whole. The central premise of this research appears to be definitive and conclusive with regards to the rural landscape retaining functional properties and elements suitable for habitat protection. However, results for the currently protected areas- RRSP and Greenbelt, LLELA, and Pilot Knoll WMA, were consistent with a general trend revealing heightened vulnerability of the current conservation network in place. There clearly is a need, as expressed in the results and conclusions of this research, for additional conservation areas to be proposed and which serve a broader purpose of landscape connectivity between protected areas. Results for the Mountain Lion Corridor movement also revealed promising signs of the overall suitability of core areas delineated by FCA 1 and 2, while also raising attention to the high level of fragmentation within and adjacent to each corridor analyzed. Although no mountain lions were proven to be present in these study areas during this research the occasional sightings of them by the public proved to be inspirational and promising. Moreover, as an indicator species of habitat quality and quantity it is reasonable to assert there are geographical areas of Denton County where wildlife can still thrive, especially for those species whom are not area-dependent but capable of utilizing smaller areas to survive and flourish.

Results for the study area, ecoregions, FCA's, and wildlife corridors suggest Denton County contains areas of high ecological functionality, moreover geographical functionality, with their overarching limitations of high conversion and development rates. The original aims to find functional space and places were satisfied after completing the coarse-filter local LSI model and the fine-filter Mountain Lion Corridor HSI model. Various areas of the study area and rural landscape contained either large segments of land over 70% suitable or pockets of suitable land between the current and proposed conservation areas. However, it is quite clear that each FCA is more or less an island between highways and cities as development and habitat fragmentation continue to carve out the landscape. Furthermore, each wildlife corridor is broken or dissected as they collide with major highways. During my survey of the FCA's and corridor passages of the study area wildlife roadkill was common along each major road in this study, especially I-35 with several deer, bobcat, opossum, armadillo, and skunk carcasses dotting the roadside. Major highways in the North Texas study area lack underground tunnels for wildlife travel with the exception of stream and river crossings where bridges allow mammals to cross underneath, for example FM-428 running through the Ray Roberts Greenbelt or the Red River defining the northern boundary of the study area.

Of particular interest in this study was implementing a conservation design based upon the existing FCA or reserve network and the GIS models. Among the corridors the distribution and dispersal of large mammals appear to be coming from the western and north of the study area with possible infiltration from the eastern forests as well. Connectivity between FCA's is largely restricted by highway crossings but large tracts of rural land with mid to high ratings allowed for an assessment of the two major unprotected corridor links. The northwestern corridor may adequately connect the LBJ grasslands and Ray Roberts Greenbelt, for example, provided minimal cross-over with highways. Nevertheless, connectivity between these functional areas is dissected by the high-volume traffic and tall concrete median of I-35 and heavily fragmented in between FCA 1 and the Greenbelt. Areas to the west and east of I-35 show a potential link between LBJ grasslands, FCA 1, and RRSP provided that further conservation areas are established and underground passage is given serious consideration. Without this barrier a connection between LBJ, FCA 1, and RRSP might be possible and help build a core conservation network for Denton County extending into adjacent counties, and thus become part of a North Texas conservation network. One possible remediation might be the construction of underground wildlife tunnels at different sections of I-35 and other major highways in the study area.

The original purpose of the cartographic models was to identify areas of potential suitability for expanding protected habitat and equally to identify areas of higher susceptibility to anthropogenic stress seems to have produced positive results. One guiding principle in the research was to spatially delineate ideal portions of Denton County eligible for real or hypothetical land acquisitions for future conservation projects. A large portion of northwestern and southwestern Denton County shows high suitability scores and is consistent with the prominence of the Lake Ray Roberts State Park and Greenbelt boundaries. After identifying highly suitable areas further analysis should include surface analysis and additional site sampling for areas with the highest prospect for landscape connectivity, including land use patterns, landowner's willingness to conserve their land and the associated economic impacts, and other pertinent variables specific to those areas. Possible funding for expansive conservation projects are indeed limited but could come from the county or local municipal governments, or more likely from The Nature Conservancy, Natural Area Preservation Association, Texas Land Trust Council, Texas Parks and Wildlife Department, or the Conservation Fund. The prospect of park expansion and connectivity is largely hypothetical and dependent upon cooperation between several private and public entities, and the local community for support. After analyzing the predicted occurrence of wildlife and realizing the potential of additional reserves in the area there is, indeed, reason to believe currently vacant and unincorporated land can be included into a larger green space network, which may or may not necessitate full protection so long as major areas are covered within a core reserve. A less optimistic conclusion, although speculative and inferential, is that the county and local municipal governments reveal only moderate environmental values, or at least a lower priority given to ecosystems, wildlife and green space in context of economic development and urbanization. However, Denton County's uniqueness is in many ways defined by its natural and semi-natural landscape in rural areas surrounding the increasingly urbanized areas, and could be a valuable and irreplaceable symbol for the collective community within Denton County and its visitors. It will require a common, coordinated plan among each municipality to protect areas of high ecological value, and this includes stronger environmental values to be implemented in the planning process and practice, and further regulated by private and public entities alike, to ensure success. The results produced by the GIS models are both alarming and promising, and may pave the way for future conservation projects and actions given proper support and further study.

With the addition of the County LSI and habitat mask it was possible to identify local areas which could be spatially verified using the 2005 aerial photo. Both conservation areas 1 and 2, and the Northwest and Southwest Corridors, fell within high suitable ranges for most of their respective areas. After the LSI was applied both conservation areas were reduced to significantly smaller areas yet equally more feasible to implement into a conservation network. Land ownership is predominantly private in both areas and along both corridors which implies that conservation strategies would entail wildlife and conservation management to be one of cooperation with private land owners and multiple municipalities. While the LSI model cannot be the penultimate authority for locating conservation areas and corridors it clearly showed geographical areas of high functionality. The identified areas can be incorporated into a county-wide conservation sensitive area network and reference for the affected municipalities. Moreover, it may also be used by private organizations and the state for future land acquisitions within these zones for conservation purposes. At the very least, the LSI model spatially delineates critical habitat within the county which could not be verified completely by the regional LSI model, and will serve as a basis for further research on each area and the county as a whole. Whether or not the areas can be adequately acquired and protected by a state or conservation agency may be secondary to how the land itself is zoned and managed. Conservation area 1, in particular, appears to be the most suitable area of the county while also offering a high degree of connectivity to neighboring counties. Yet it is also part of unincorporated Denton County which handicaps zoning and land use policies that might be more effective in a municipality. At the same time it may be free of those constraints. That each conservation area and associated corridor satisfying the iterative methodology include portions of Denton County's historical waterways, Clear Creek and Denton Creek, makes their protection more meaningful from a cultural perspective as well. There clearly are biogeographical and cultural reasons for conserving functional places and space yet it remains up to the people of North Texas, Denton County and multiple cities to express concern and care in their preservation. To do so will imply strengthening laws and policies, allocating money to land acquisition and to conservation organizations, and to protecting species who migrate through and live in these areas. Moreover, to do so will also demand considerable restraint, a voluntary one, from those who are in the greatest position to determine who owns the land and how it is managed. If it is unfeasible and impractical to designate new protected areas it will still be, nevertheless, critical to respect such areas as a society, community and as an individual. Merely knowing of them may be enough, getting lost within them more so, and finding a way to protect them as emblems of naturalness a goal we may reach for in its illusiveness and impracticalness. Whatever the outcome may be it is clear that natural areas do remain intact, even if marginal as a whole or at their edges, and we may find peace in their presence within the landscape as we drive through and by them, or if we are fortunate enough to be pleasantly and comfortably lost within their boundaries, able to hear complete silence and able to see complete darkness without the protrusion of automobiles and lights.

APPENDIX A: SUPPLEMENTARY MAPS

Figure A1: One of Denton County's only privately created and owned conservation areas facilitated by the Natural Areas Preservation Association (NAPA). Area under conservation easement includes over 70 acres of Bottomland Hardwood forest, and natural prairie.

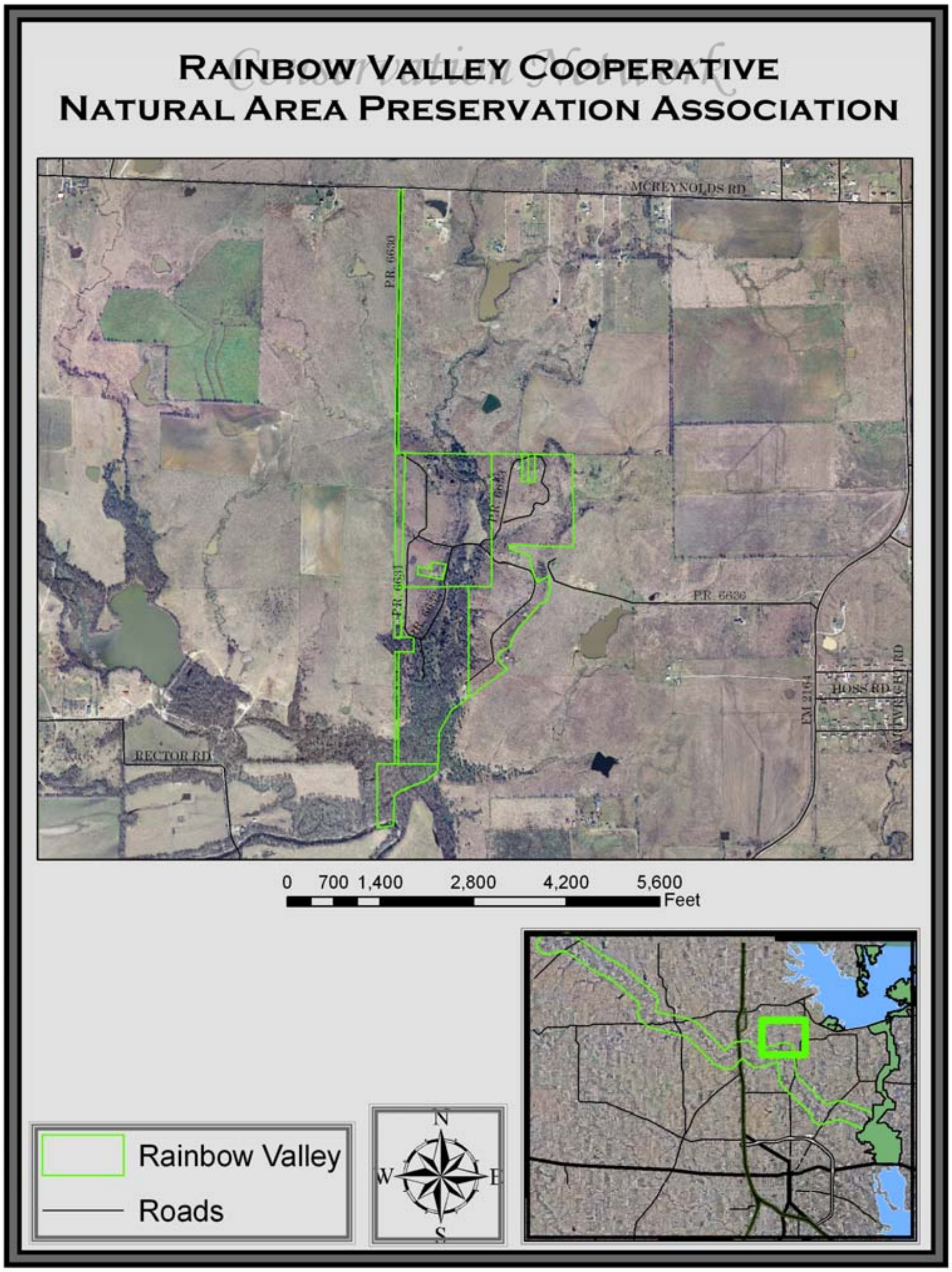
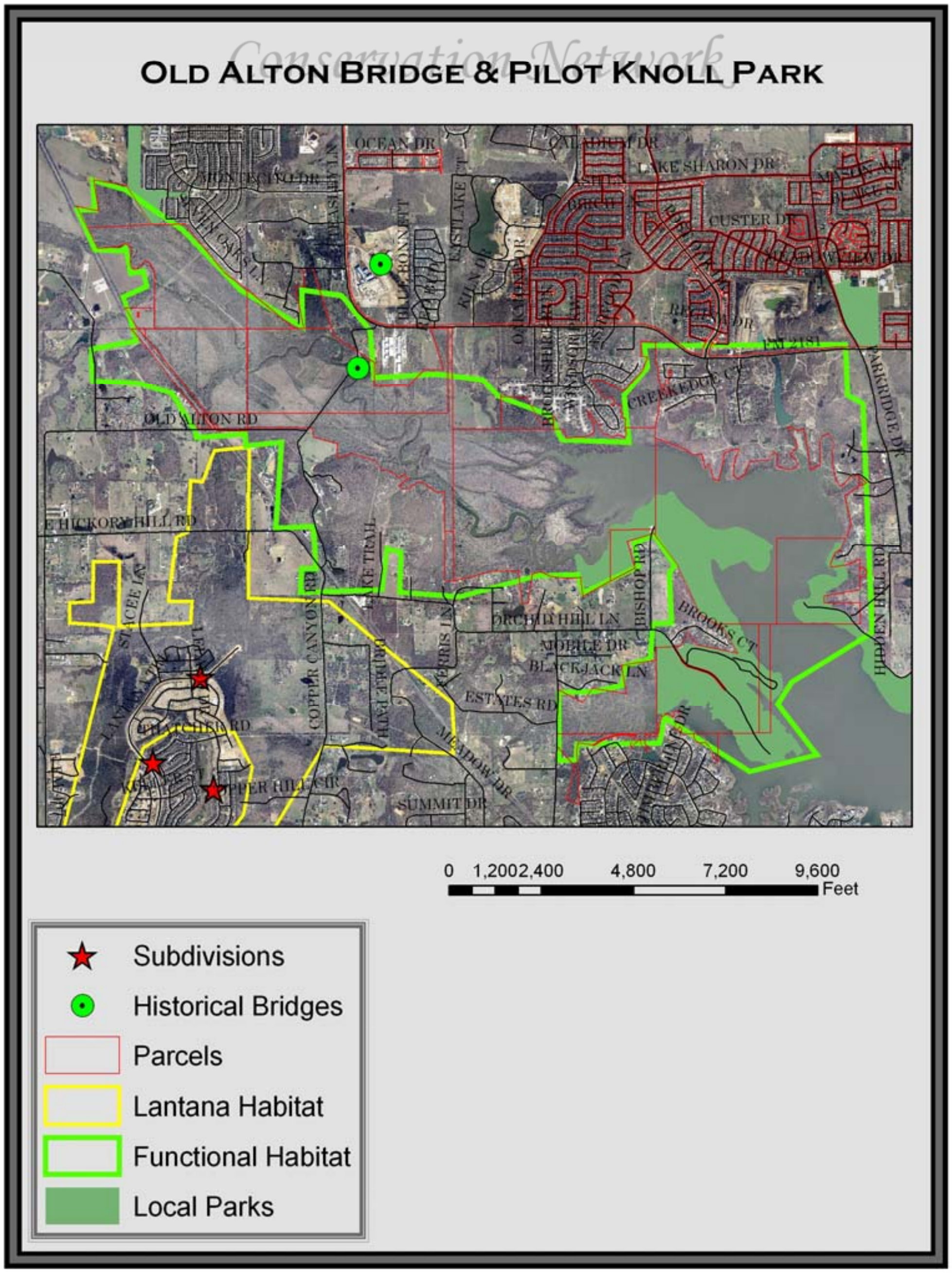


Figure A2: Relatively natural area within vicinity of Lantana Subdivision, including Pilot Knoll Park, Old Alton Historical Bridge, and Wildlife Management Area along Old Alton Road. The area has received reports for numerous wildlife species.



APPENDIX B: PHOTO GALLERY

Photo 1: FM 51 Underpass within the boundaries of FCA 1.

Photo 2: FM 51 Underpass within the boundaries of FCA 1.

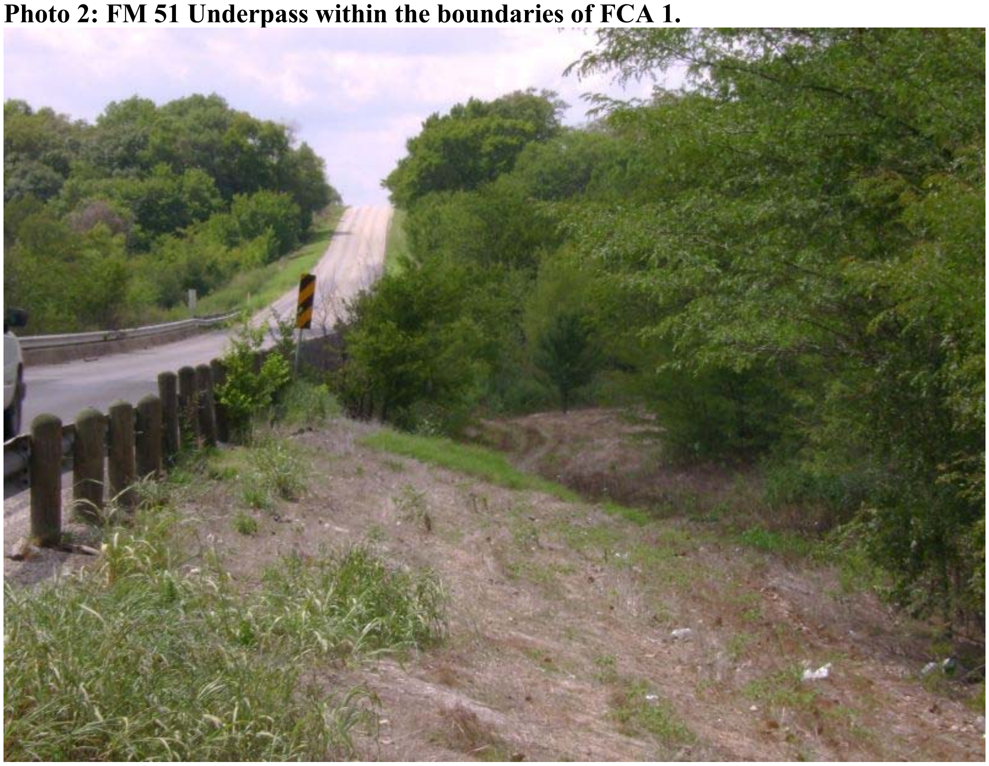


Photo 3: FM 455 Underpass near Bolivar and west of Sanger.

Photo 4: FM 455 Underpass near Bolivar.

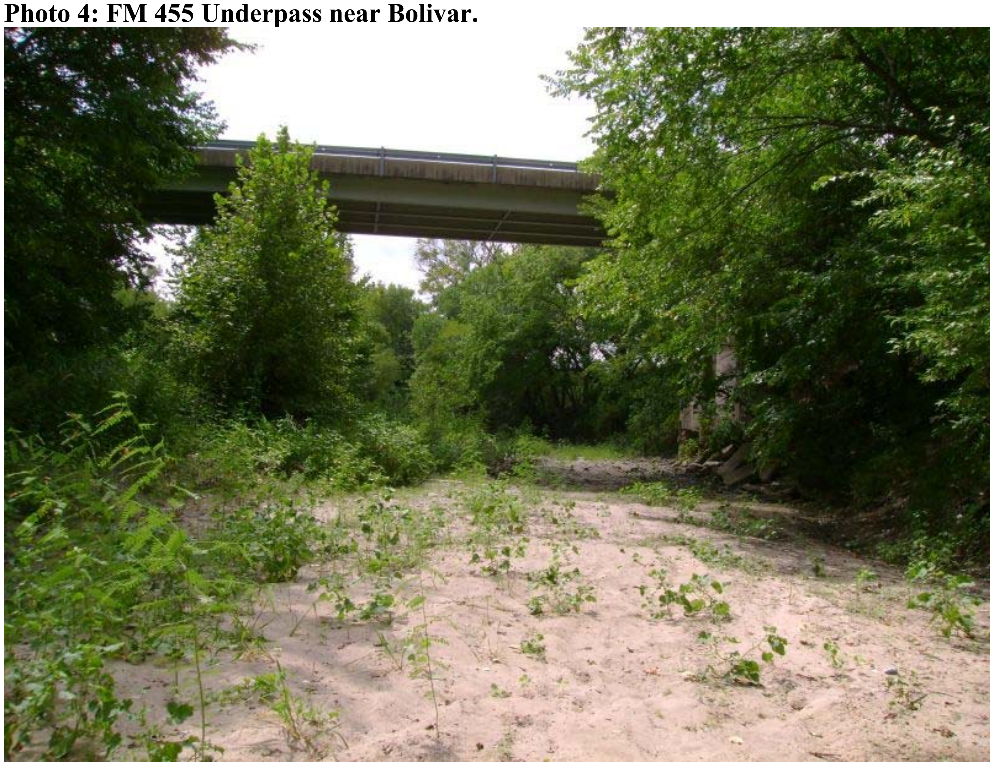


Photo 5: I-35 Underpass along service road near Sanger. This was the only I-35 Underpass where wildlife appear to be able to migrate across.

Photo 6: I-35 Underpass near Sanger.

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